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OMMON COMMODITIES
AND INDUSTRIES

THE ELECTRIC LAMP INDUSTRY

G. A. Percival

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THE ELECTRIC LAMP INDUSTRY

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By courtesy of the *Edison Swan Electric Co., Ltd.*

STANDARD PHOTOMETER FOR LAMP TESTING

Per.

PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

THE
ELECTRIC LAMP
INDUSTRY

BY

G. ARNCLIFFE PERCIVAL

IN COLLABORATION WITH ENGLISH AND AMERICAN
CONTRIBUTORS

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PREFACE

While electric lamp manufacture is essentially a scientific industry, the short account in the following pages is not intended as a technical treatise.

Certain data has necessarily been introduced to make the description more complete, which leaves parts of the text open to criticism by those engaged in lamp manufacture.

In the preface to most books one usually makes a formal acknowledgment of assistance, but in the present case it is doubtful if the work would have been compiled if the writer's colleagues had not offered such generous help.

During a period of severe illness and also while in America the author found the value of many friends, and desires to express publicly his appreciation of help from Dr. W. Phillips, who vigorously but kindly "blue pencilled" the original copy in the interests of future readers; also to Mr. Paul Freedman for his help in connection with the material in the chapter on vapour lamps and to Mr. S. B. Staines for his efforts in collecting the illustrations.

To this must be added the acknowledgment of assistance from many friends at the Edison Swan plant; to the management of the several companies referred to in the text, who have given both information and illustrations freely, and to the journals of the various technical societies in England and America.

G. A. P.

October, 1920.

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HISTORICAL

Over a hundred years ago, at the Royal Institution in London, Sir Humphry Davy first demonstrated a beautiful effect of producing light between two pencils of carbon. In this early experiment 200 grove cells were necessary to produce sufficient energy for the desired effect, a reason which prevented any real development in this direction until Faraday, in 1830, built a machine demonstrating his theory of electro-magnetic induction, which, as an early form of dynamo, generated electrical current which facilitated further work on the early carbon arc lamp of Davy.

From this time on things moved very rapidly, as, while science was studying the new phenomenon, so commercial possibilities were indicated.

The result was that an invention was claimed by Thomas Wright, of London, for preventing, or rather correcting, the unequal burning of the carbon pencils, by using an automatic device which maintained a constant distance between the incandescent points. Rapidly upon this came other improvements of a like nature—notably those of Duboscq and Holmes, the latter having built a powerful electric generator similar to the one originally made by Faraday.

A period was now reached when a reasonably simple type of automatic carbon arc lamp had been produced together with the new machine giving very considerable current, the result being that electric lighting became a commercial possibility.

One of the earliest records of application to a useful purpose is that of the installation in the South Foreland lighthouse by Duboscq, followed in 1862 by the Holmes improved lamp, which, on a clear night, could be observed from the cliffs of France.

Although the invention of the dynamo by Gramme in 1870 added so largely to the possibilities of electric lighting for general purposes, there appears to have been a lull in the interest until the introduction of the "Jablochkoff Candle" (called after the inventor, M. Jablochkoff) in 1876.

Two sticks of carbon were set parallel to each other with an insulator between composed of china clay, the points being joined together with a metal paste. When the current from the Gramme dynamo was switched on the paste rapidly became incandescent, finally melting and creating an arc between the carbon points. As the carbons burned the insulator was volatilized, so maintaining a steady light until the carbons were consumed.

Although later alternating current was used, which equalized the burning of the carbons, the difficulty was overcome in the Jablochkoff candle by using one carbon larger than the other, but the greatest defect was due to the short life of one-and-a-half or two hours.

In spite of this, it was in many respects superior to the gas then being used, for which reason many began to adopt it, amongst whom were the Opera House, in St. Petersburg, and the Gaiety Theatre, in London.

The inventions of Brush, in 1878, made a great difference in the possible application of arc lighting, from which time on improvements were made, firmly planting the new form of illumination on a sound and economical basis.

Whilst the arc lamp had, and has now, a very large sphere of usefulness for domestic, industrial and similar purposes, the disadvantages are very considerable in consequence of the attention required for renewing the carbons, the great intensity of the light, and the bulky form of the mechanism necessary for feeding the carbons as they burn away. For large rooms, workshops, and street lighting these disadvantages are compensated for by the high efficiency of illumination obtained as against the small current consumed, but in rooms of ordinary size such a type of lamp would be unsuitable.

The names of Swan and Edison are usually associated with the invention and development of the incandescent filament lamp, but a long time previous to this the idea of making a wire the light-giving medium had occurred to others. Even as far back as 1842 Moleyns took out a patent for using platinum wire as a resister, but Starr, of America, really produced the first true filament lamp, an invention which might have had far-reaching effects had not death visited him at the early age of twenty-five.

As in the case of the arc lamp, when it was realized that an improved type of lamp might be possible, many investigators engaged in trying to develop a practical commercial lamp after the type invented by Starr, who, no doubt, conducted more experiments than have been recorded. There is little of real importance, however, to learn from the point of view of the electric lamp industry as it is to-day, before the advent of the carbon filament in 1880.

In the autumn of 1879, rumours began to circulate that Thomas A. Edison of America was about to introduce as a commercial proposition a new lamp which would compete very successfully with coal gas for lighting purposes. Shareholders in the various gas undertakings began to get nervy, and something approaching a panic was caused when Edison made public the nature of his invention in 1880.

With the characteristic energy of his countrymen, Edison soon had demonstrations in every part of the world. The Bowery, in New York, and the City Temple, and Post Office in London, soon installed the new lamps, while Paris and Rome were erecting plant for the same purpose Everyone became interested, and thousands of people made a point of visiting the exhibitions or thoroughfares where the new lighting was to be seen. Edison became the hero of the hour. Then came the climax—Joseph Swan claimed anticipation of the Edison master patent. Litigation followed which might have had serious effects, but the two parties, realizing that they both had an equal claim to the invention, decided to join forces, the result of which was the creation of the Edison and Swan United Electric Light Company to carry on the business in England.

In view of later events, and as an epoch of scientific and industrial importance, a brief review of the work of Swan and Edison will be of interest in following developments later.

At about the age of seventeen, Swan, a keen lad of the stuff made in the North of England, became interested in making a platinum wire glow by passing an electric current through, such as was done by Starr. For fifteen years Swan made experiments quietly and persistently, with a view to substituting the platinum. One of his great difficulties was due to the oxidation of the filaments which he used, as at the time of his earlier experiments no means of obtaining a thoroughly good vacuum was known, a difficulty experienced also by Starr.

It is interesting to note that apparently both Swan and Edison endeavoured to use filaments made by cutting fine strips of paper, carbonising and mounting in a glass bulb afterwards evacuated. In both cases the method was found to be useless on account of the extreme fragility of the product.

Swan, however, conceived the idea of using a thread of cellulose, which was carbonized by immersion in sulphuric acid and careful washing with water. The carbon skeleton thus obtained was further made more dense by baking in graphite, and gradually brought to a very great temperature during a long period, which treatment added considerably to the strength of the filament produced.

In February, of 1879, the inventor, who had been working for so long upon the carbon filament problem, produced at a meeting of the Newcastle Chemical Society his new lamp, which curiously enough did not cause the great public excitement which one would have expected.

While Swan had been quietly at work, Edison was also busy completing his inventions which gave such impetus to the industry throughout the world.

As already mentioned, the carbonized paper filament proved a failure, and, like his contemporary, Edison sought a more suitable medium for making his lamp.

In connection with these researches, one is fortunate in having more opportunity of following the work carried on in America in greater detail than is the case with Swan. For those who are sufficiently interested, reference to the life and work of Edison will prove how determinedly he set out to accomplish a desired result —how for days and nights he and his staff kept steadily at work in their endeavour to perfect a process only then in its infancy.

One result after another was "scrapped," until it was found that a particular species of bamboo could be cut into fine rods which proved suitable for the purpose in view. With that quick decision peculiar to the Americans, commissions were sent to all parts of the globe to investigate and report on the suitability of different kinds of cane for making lamp filaments.

Edison made his announcement in the October of the same year as Swan, from which time on the carbon filament lamp made tremendous headway, largely owing to the improvement made by Swan in the manufacturing process of the filament.

As the demand for lamps increased, simplified methods were introduced to enable a thoroughly satisfactory lamp to be marketed in competition with the gas interests. The new filament made this possible largely in consequence of the cheapness and certainty in production.

The process was in principle that now used for the making of artificial silk—and probably gave rise to that industry—of dissolving cellulose in a suitable medium, such as zinc chloride, and squirting through a glass jet into a coagulating fluid. The strands of gut-like material on being carbonized and baked form the filaments.[1]

For several years after the merging of the Edison-Swan interests, while little improvement was made in the lamp industry, its rapid growth as the outcome of the superior illuminating and hygienic effects over the dirty, ineffective, batswing gas burner, made it necessary for some radical change if gas lighting was to hold its own. The invention of Welsbach and the introduction of the incandescent gas mantle therefore came at an appropriate time, and threatened the electric lamp makers with the boomerang which they had hurled a few years previously. Competition naturally became very keen, and research laboratories became necessary adjuncts to all the forces engaged, particularly as

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[1] Details of this process are described in the chapter on filament making.

Germany was now rapidly threatening revolutions in hitherto quiet monopolized markets. Efforts to run the carbon lamp at a higher efficiency resulted in so shortening the useful life of the lamp that the proposition became uncommercial.

In 1898, Nernst, of Gottingen, who had been experimenting on the conductivity and emmissivity of the rare earths, found that some substances, such as zirconia, which were electrical insulators at normal temperatures, when heated to a dull red became sufficiently conducting to enable a white heat to be produced, at which temperature a greater amount of light was given for the current consumed than was the case in the carbon lamp. One considerable advantage was that the filaments had not to be mounted in vacuum, but could be burned in the open air, but against this were the difficulties of manufacture, the brittleness of the zirconia rods, and trouble in lighting up, which could only be accomplished by a preliminary external heating, or by the use of auxiliary mechanism which added to the weight, cost and bulk of the lamp.

However, the fact that the Nernst lamp took only 1·5 watts of electrical power as against 3·3 watts for one candle-power of light with the carbon glow lamp, soon gained for it a wide reputation, and with new improvements there is little doubt that it would soon have found a very much larger market had not the introduction of new types of vacuum lamps with metal filaments been introduced about the same time.

Peculiarly enough, the inventor of the gas mantle also proposed the use of osmium for use in electric lighting, but the rarity of the mineral and difficulty of preparation of the metal in the form of wire debarred it from anything like a successful commercial proposition. The suggestion proved of value in stimulating research upon the properties of metals of higher melting points, and in 1903 Siemens and Halske, of Berlin—a further contribution from Germany—announced the successful results of lamps with a tantalum filament.

As with all new inventions in the electric lamp sphere, there was at first certain trouble in producing material of sufficient purity, but with the plentiful supply of the ore which existed from which tantalum is prepared, these difficulties were soon overcome, and the new lamp soon became widely used on the Continent, in England and America, consuming the same power as the Nernst lamp, with certain very distinct and obvious advantages.

From about 1890 numerous inventors took out patents improving on existing lamps, but very few were of any consequence, and the chief advantage was derived by the Patent Office, which increased its revenue.

Mention may be made here of lamps on an entirely new principle made by Arons, Lummer and Hewitt, which may have very considerable developments within the next few years on account of the very high efficiency of the candle-power yielded.

By passing current through an atmosphere of mercury vapour contained in an exhausted vessel, a brilliant green discharge is obtained, having very high illuminating properties. With the so-called vapour lamps it is necessary to strike an arc before the discharge can be obtained, this operation being performed either by tilting—in the case of a tube—or shaking to close and break the electrical circuit rapidly, or (by passing a high tension current through) applying a high voltage to jump across the gap, and then switching on to a normal voltage of from 50 to 100 volts. The lamp has no filament, but two electrodes, one of mercury and the other of iron or a similar material. The effect of the green light emitted from the mercury vapour lamp is somewhat unpleasant, giving a rather weird ghost-like effect in consequence of the lack of red rays. With an efficiency of 0·6 watts per candle, the lamp has naturally very many applications, especially for outdoor lighting. Recent experiments for overcoming the objectionable colour of the light by introducing cadmium have met with considerable success, adding certain of the red rays to the light with a view of creating a more natural colour effect.

The successful issue of the tantalum lamp was rapidly followed by an Austrian improvement.

It had been reasonably imagined that if metals of higher melting point could be used in place of tantalum, the light would be proportionately increased. Platinum had been used in the earlier stages, osmium was not a commercial product, tantalum was successful, but yet other elements had not been tried.

Tungsten with a melting point of 3200° C. (half the temperature of the sun) might be used, but it was known to be an extremely hard, brittle metal.

Just and Hanaman, of Vienna, prepared a tungsten filament by heating a carbon filament in an atmosphere of tungsten oxychloride, the carbon and tungsten changing places, but the filament so made was not altogether satisfactory, and a rapid succession of patents were taken out by the same parties covering other methods of producing the desired effect. Kuzel, also of Vienna, made filaments of a similar nature from what is known as colloidal tungsten, but the most successful filament of this metal was produced by the Deutsche Gasgluhlicht Aktiengeselschaft by reducing pure tungsten oxide in hydrogen to a fine black metal powder, a very simple process. The tungsten powder made into a paste was forced through dies to obtain the desired form.

The details of the process are of considerable length, and it is not within the scope of this very limited space to describe what is now an obsolete process, but the lamp had its day like its predecessors, with a very economical production of light, but rapidly died out on the announcement by the General Electric Company of America of the manufacture of drawn, ductile, flexible tungsten wire in any size.

Whatever may be the technique of the patent question one must, in fairness, acknowledge the hard, painstaking work of Dr. Coolidge and his colleagues of the above company in what may almost be termed a classical investigation—the effect of which was to revolutionize the lamp industry and throw some of the most up-to-date technical literature behind the times.

Hardly had America given to the world the strong, efficient, cheap drawn wire lamp than it was followed by a more " brilliant " invention, known as the half-watt lamp, being as perfect, as far as one can imagine, as an electric filament lamp can be.

One addition now remains to be mentioned in this very inadequate review of an industry, the growth of which has been phenomenal.

The Edison-Swan Company, of England, whose association with lamps has always been a household word, have recently placed upon the market a most ingenious lamp of high efficiency, which, although in principle is of the arc type, has none of the disadvantages of the ordinary arc lamp. The light is emitted from a small tungsten globule contained in a sealed glass bulb, a fact which, apart from ordinary uses, makes it particularly useful where a point source of light is required, such as in microscopical or kinematograph work.

It may be that within the next few years improvements will be made which will again change the nature of electrical illumination, as has been the case so many times within the last century.

Scientific methods of control and research are now an essential of every large lamp factory, and while such is taking place within the laboratory of many works, it is not probable that the description of the "Electric Lamp Industry" in these few pages will be out of date when published.

ELECTRIC LAMP INDUSTRY

CHAPTER I

GLASS MANIPULATION : PUMPING EQUIPMENT

FLINT glass is invariably used in lamp making, the manufacture of which is described in detail in another volume of this series.[1] It contains a large percentage of lead, and is easily worked in the blow-pipe flame.

In making lamp bulbs a quantity of molten glass from the pot is gathered on the end of a long tube five feet long, an operation which, although apparently simple, requires very considerable skill in gauging the right quantity. Withdrawing the tube, the glass worker holds the hot ball of metal away from him at a few degrees to the horizontal, rotating the tube all the time to maintain the spherical shape of the glass taken up. The other end of the tube he inserts in his mouth and blows gently, still rotating. Having got the " metal " in condition, it is dropped into a mould made in two sections, both of which are closed together by a boy as the glass on the end of the tube is inserted. Still rotating, the tube is blown, which forces the malleable glass to the shape of the mould, from which it is withdrawn when set and cracked off the end of the blow-pipe, afterwards being annealed.

Glass tube, of which large quantities are used in the factory, must have the same composition as the bulbs, otherwise satisfactory joints are not possible and losses occur owing to cracks.

---

[1] *Glass.* P. Marston.

In equipping the work bench in the factory and in the numerous operations throughout, a good knowledge of glass manipulation is, if not absolutely essential, at any rate desirable, even with the many automatic machines for replacing hand labour. Joints in circuits are having to be continually made, and to obtain thoroughly good vacuum tight joints requires skill and practice.

Two kinds of blow-pipe are used, each being capable of alteration and adjustment while in use. The cannon blow-pipe is fixed to the bench, the flame being directed away from the worker. A large or needle flame can be obtained at will by reducing or increasing the gas supply until the flame is regulated to the desired size and intensity. The hand blow-pipe is used where the work cannot be brought to the blow-bench. This is similar to the burners used for oxy-acetylene welding, being connected to gas and air pressure by lengths of rubber tube. The flame can be easily regulated by slightly pinching the air tube, or, as is provided in many patterns of this kind, by rotating a milled wheel with the thumb, which opens and closes the air supply, so giving a luminous, large or fine flame as desired without having to use both hands.

In working with lead glass it is very important to use the extreme part of the flame, or otherwise a dirty black mark is produced, due to the reduction of the lead in the glass to the metallic state. If the patch appears whilst working, by moving the flame further away from the work, the lead is again oxidized, so clearing the glass, but if allowed to remain the reduction takes place further into the body of the glass, when no amount of re-heating will clean it up.

In fitting up or repairing joints on the pump bench, the glass tube is cut to length and laid out so that the ends to be joined come close together. The glass is gently warmed by fanning with the blow-pipe, and the two opposite edges of the tubes melted and brought centrally opposite. Heating is continued until no joint is visible and a perfect weld is produced. When the two sections to be joined are open at both ends the glass tends to close up or fall in during heating, so in working it is usual to close one end by a rubber cap and attach a length of rubber tube to end of the other section, so that should the glass begin to collapse it can be forced out again by very gentle blowing through the flexible connection which for convenience may be held in the mouth during the jointing. For joining capillary tubing the ends are widened out a little, first to avoid any risk of the bore becoming blocked, and also to facilitate a more even heating of the edges which have to be joined.

In all glass work of this nature it is very necessary to have the glass clean and dry, and after finishing the work to anneal the portion by gently warming and reducing the heat.

Many instances occur where it is either impracticable or unnecessary to make blown glass joints; rubber connections may be substituted or a weld to a metal pipe made by the use of an intermediate section.

In making the former, soft, red, seamless rubber tube with heavy walls is used, the glass being rounded off in the blow-pipe and a little Chatterton compound worked on to the surface whilst warm. The glass is then inserted in the rubber sleeve to make a flush connection with the opposite section. Where necessary, as an additional precaution, the joint may be held in a mercury or oil cup.

Sometimes rubber connections are not possible on account of undue heat in the proximity, in which case a platinum soldered connection makes an excellent joint between the glass tube and metal. For this purpose platinum is deposited for about one-eighth of an inch from the end of the glass and the metal tube opened to make a sleeve over the platinum. Solder is then melted on with a fine blow-pipe, thereby making an airtight weld which, however, must not be subjected to too much strain.

Stop-cocks are invariably necessary in some parts of the pump system, and unless carefully made and well ground in, perfection in the other parts counts for little. The type varies according to circumstances, and may be plain or sealed, with two or more legs. The lubricant used can be beeswax and oil, rubber tap grease or phosphoric acid. Before inserting the cock in the system the plug is removed and cleaned with a dry duster to remove any trace of grit, washing if required in benzole. The same treatment is directed to the barrel. A thin film of lubricant is applied evenly to the plug, which is then inserted and worked round in the barrel until the grinding becomes evenly transparent. Any white streaks indicate that the two surfaces are not in contact, a trouble which may be caused by dirt or faulty grinding of the cock.

In arranging the pumping bench it is necessary to provide a means for testing the degree of pressure as the exhausting proceeds, one of two methods usually being adopted—

(1) A high tension transformer giving about 10,000 volts is connected to the leading wires of the lamps through a simply operated switch on the bench, the other terminal being earthed.

As the air is pumped out of the lamps a discharge in the form of wavering sparks of a violet tint shoot from the filament to the side of the bulb. As the exhaustion is continued the lamp is lighted up by a violet glow of rather uneven appearance, which rapidly changes to a redder tint and then becomes white and milky; the light becomes streaked with alternate bright and dark lines. Eventually the whole bulb fluoresces a bright green, blue or red, according to the nature of the gas, which effect ceases as the vacuum becomes higher when no discharge can be produced. This indicates that the amount of air in the bulb is so slight that the discharge cannot pass, a sign that there are no leaks, and that the pumping is proceeding satisfactorily.

(2) The other method depends on the principle of trapping and measuring the pressure of gas in the lamp at any period after the rough exhaust.

The instrument for this purpose is known as the McLeod Gauge (Fig. 1), many types of which are made with small variations.

Before exhausting, the mercury in the long tube is level with the surface in the reservoir, but on pumping the level in the tube gradually rises until the difference between the two surfaces exactly corresponds with the height of the barometer. This is a rough indication of the degree of vacuum, but to measure very accurately the reservoir is raised so that the mercury in the column flows into the bulb and so traps any residual gas which it contains. The mercury rises also in the side tube, and is brought to a level with the top of the bulb extension by careful adjustment of the reservoir. The difference of the heights of the two columns is a measure of the pressure upon the air confined in the bulb.

Ramsey and Bailey investigated the accuracy of the McLeod gauge, and found that while giving fairly accurate results in the case of dry hydrogen and other gases, it was quite unsatisfactory for air and carbon dioxide. In fact, two gauges on the same circuit will invariably give different readings due to the surface condensation of carbon dioxide on the glass. When exact readings are required, the apparatus is washed out with dry nitrogen, when the observation is more truly indicative of the pressure.

The most elaborate instruments for testing the vacuum are rendered useless unless pumping equipment of the highest grade is used.

A pump must have two essential qualities—viz., rapid and high exhaust. The older types of mercury pump gave the latter, but were slow, while many of the mechanical oil pumps possessed just the reverse properties. In addition to the bench pump it is necessary to have a backing pump to obtain anything like good efficiency, such machines as those used for vacuum cleaners and vacuum drying ovens usually being used. Such machines will have a capacity of from 4 to 400 cubic feet per minute and produce a vacuum to within half-an-inch of the barometric height.

The back or "rough pump," as it is often called, is so connected to the bench that it is continually drawing on the "top" pump, so relieving it of additional work and reducing the time of exhausting, but to further reduce the strain a secondary pipe line is arranged by means of which the greater portion of air is removed from the lamps by the rough pump first, and only after this preliminary exhaust, taking perhaps half-a-minute, is the top pump brought into service.

Although the rough pump may be selected with comparatively little care, the high vacuum is an extremely important factor, and requires an intimate knowledge of the technique if good lamps are to be produced.

Two sets of pumping equipment may be described

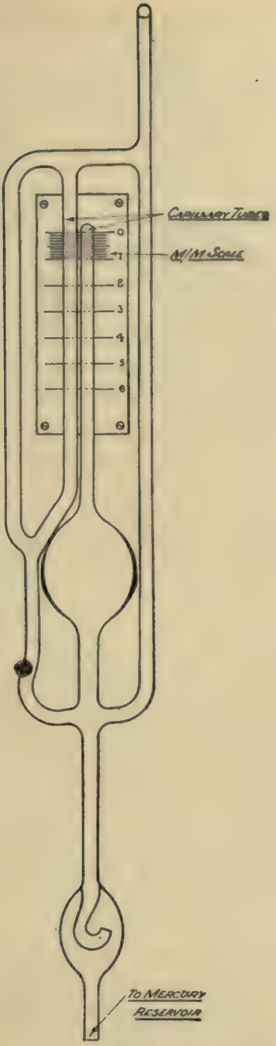


FIG. 1

McLEOD GAUGE FOR MEASURING VACUUM

as typical of American and German practice, the former usually being oil as distinct from mercury pumps usually used in Germany and Austria.

The May-Nelson pump is American made, and of very excellent construction. It requires only ⅛ h.p. to drive it, and while only covering a base area of 12 in. by 7 in. is very rapid in action, with a displacement of 930 cu. in. per free air revolution. It produces a vacuum 0·25 mm. on a McLeod gauge in 25 seconds.

It embraces features which highly recommend it for industrial purposes, especially for continuous working, as it has no valves to stick or leak, and is not affected by moisture or slugs of liquid passing through. The pump, while running in oil, is not an oil-sealed pump.

Another American pump of very recent type is the one made by the Central Scientific Co. of New York, which is very efficient for production of high vacua. For reducing the pressure, even of large containers, no backing pump is necessary for a pressure of 0·001 mm. It is provided with a " cut off " to prevent sucking back, and will run continuously on ¾ h.p.

Such pumps as the ones described may be used in sets of two or three, one pulling on the back of the other, by which means very high readings may be obtained, but it occasionally happens that an extremely high vacuum is necessary when an entirely different pump is used in conjunction with the oil pump. The credit of the vapour pump, as it is called, is due to Langmuir, a description of which is particularly interesting as utilizing an entirely new principle.

A bulb A, which may be of glass (*see* diagram, Fig. 2) contains mercury and mercury vapour, which, produced by means of a heater B, passes through the curved tube C into the condensing chamber D. The annular space E, between this tube and the condensing chamber,

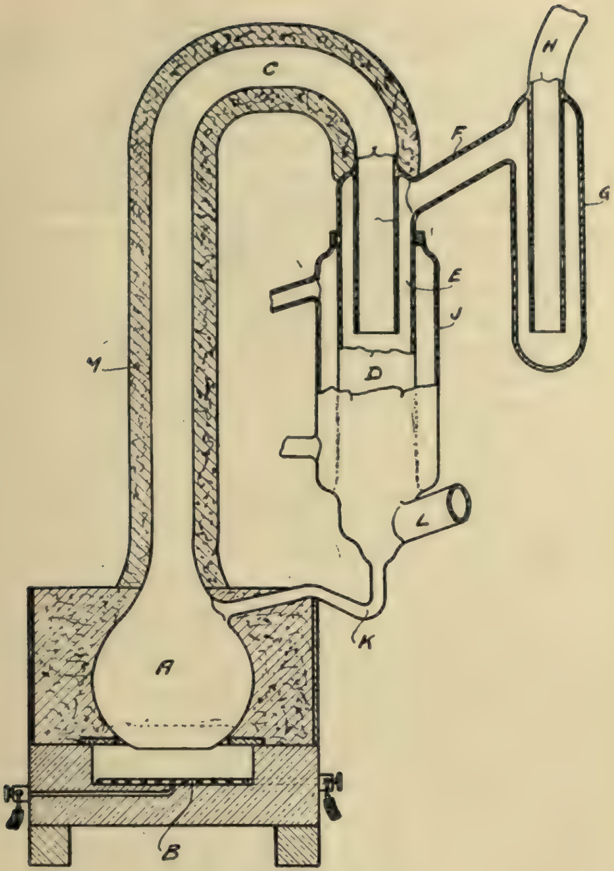


FIG 2.

"LANGMUIR" HIGH VACUUM PUMP

communicates with the conduit F, which in turn is connected to the trap G, while another conduit H furnishes communication between this trap and the vessel to be exhausted. The walls of the condensing chamber D may be kept cooled by means of water circulating in jacket J surrounding the condensing chamber. The condensed mercury falls to the bottom of the condensing chamber and is returned to the bulb A through the tube K. The conduit L communicates with the oil pump, which produces a vacuum somewhat lower than the vapour pressure of mercury at the temperature at which the bulb A is maintained. The bulb A and tube C are covered with a heat insulating material M.

In operation a slight flow of mercury vapour pours through the conduit F to the trap G at a pressure of about two microns, that is, a pressure corresponding to the vapour pressure of mercury at ordinary temperatures. By cooling the trap G with liquid air this vapour is condensed. The gas which is being pumped out of the receptacle has to flow through conduit F in opposition to this stream of mercury vapour, and the larger this conduit is made the greater will be the opposition offered by the mercury vapour to the flow of the stream of gas which is being removed. By subdividing the conduit through which the gas is removed into a plurality of narrow passages or diaphragms separated by spacing blocks, this difficulty may be overcome to a large extent since a large part of the pressure of the mercury vapour will be expended upon the walls of the passages instead of in opposing the fluid of gas away from the receptacle.

The Gaede rotary box pump is illustrated in the diagrams (Fig. 3) which show a vertical section and a section parallel to the axis of the shaft. The shaft B carries the cylinder A in which the hardened steel valves move

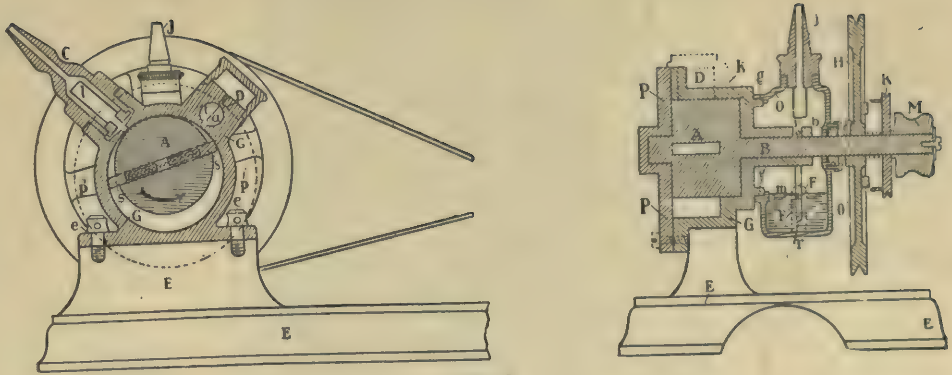


FIG. 3

GAEDE ROUGH PUMP

radially. The valves are pressed outwards and against the inner wall of the red brass casing G by springs. The front of the casing is made air-tight by a polished red brass plate P (without packing). The plate is firmly fixed by seven screws to the flanges of the casing G and put in position by two adjustment pins. The casing is mounted on an iron plate E and fixed with two screws "e." Chamber O serves as an oil vessel and air chamber, and is screwed to the casing by means of the thread "g." The vessel is filled up to "m" with oil, and oil supplied to the axis by the ring "r." The glass window F serves to control the correct amount of oil, the stuffing box "b" preventing the escape of air from O. The grooved wheel H is fixed to the shaft B and is connected by a belt to the motor, also mounted on the iron plate.

When the cylinder A rotates in the direction of the arrow, the air is drawn through C and forced through the valve D along the passage "k" to the air chamber O. In the suction nozzle C is placed a sieve of narrow mesh "l," which retains all solid particles, especially pieces of rubber which become loose in old rubber tubes and are torn off by the air current, drops of mercury, etc., so that the pump runs evenly and regularly, even without being attended to. The valve consists of the valve disc "a," which is held down on the valve seat by the spring "t." For machine driving a $\frac{1}{8}$ h.p. motor is sufficient. A series motor without starting switch can, therefore, be employed, and the pump is started by simply turning an incandescent lamp switch mounted on E.

The pump draws 110 ccm. at each revolution. The yield of the pump depends upon the number of revolutions, and also on the power of the driving motor. The pump driven by a $\frac{1}{8}$ h.p. motor evacuates a six-litre vessel from one atmosphere to 3 mm. in a minute, in two minutes to 0·4 mm., in three minutes to 0·15 mm., in eight minutes to 0·035 mm., in ten minutes to 0·012 mm., and in fifteen minutes to 0·006 mm. of mercury, readings being taken on the McLeod gauge, with rubber connections and no oil seal or drying agent.

FIG. 4

PUMP BENCHES, OSRAM LAMP FACTORY

The rotary pump is usually used in connection with a Gaede high vacuum pump producing a very high exhaust, but just as the vapour pump is used in connection with the oil immersion for very high vacuum work, so the molecular pump is very often used for similar purposes.

A comparison of the efficiency of the molecular pump with that of the mercury high vacuum pump may be made by reference to the following table, showing the average pressure with the two pumps during the exhaustion of the six-litre vessel at 10 mm., using in each case a rotary pump for the roughing out.

Gaede High Vacuum Pump Using Phosphorus Pentoxide. Pressure in mm.		*Gaede Molecular Pump Without Drying Agent. Pressure in mm.*	
After 5 mts. .	0·009	After 2 mts. .	0·000
,, 10 ,, .	0·0003	,, 3 ,, .	0·00001
,, 15 ,, .	0·00001	,, 4 ,, .	0·000002

It will be seen, therefore, that the condition produced by the mercury pump in fifteen minutes is obtained by the molecular pump in three minutes and without the use of drying agents.

This pump is entirely different in principle from the vapour pump, and has proved particularly useful in the rapid production of high vacusa, since it not only acts more rapidly and produces lower pressure than any known pump, but offers the additional advantage of removing gases and vapours without the use of liquid air or chemical agents.

There are in addition many kinds of thoroughly efficient pumps, those described being examples of each, but without regular attention and careful supervision the best pump will rapidly wear out, and it is usually preferable to overhaul apparently perfectly running pumps rather than wait for a breakdown or the return of a batch of lamps before giving the hub of manufacture the attention required.

CHAPTER II

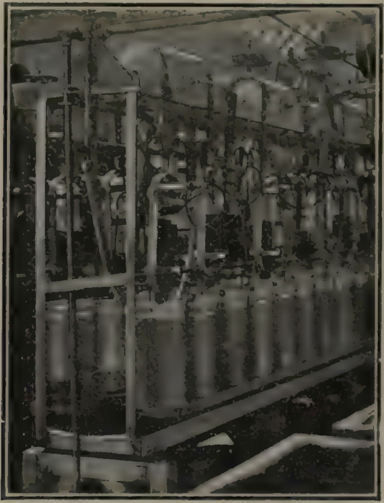
PREPARATION OF FILAMENT

The universal process now used for the filaments in carbon lamps is that invented by Swan.

The Filament. The best quality cotton is dissolved in zinc chloride solution to form a jelly like mass, and is then reduced in density to allow filtering through platinum or porcelain filters. After repeated filtering to remove suspended matter, the mass is brought to a definite viscosity and placed in the vessel for squirting.

The squirting apparatus consists of a wide glass tube brought to a bottle neck at both ends and fixed vertically on a stand so that the bottom end comes over the jar for receiving the filament. A connection is made at the top of the squirting chamber so that pressure or exhaust can be applied as required. The die for squirting through is made from glass with the bore correctly drilled to produce the right diameter filament.

Having filled the chamber with cellulose solution (cotton in zinc chloride) the mass is raised to about 70° C. while suction is applied. When quite free from air bubbles, which would spoil the filaments, air pressure is applied and the solution is forced in a steady stream through the glass jet into the receiver underneath, containing alcohol with 10 per cent. of hydrochloric acid. It at once hardens in this liquid, the hydrochloric acid counteracting any excess alkaline effect which might take place. After remaining in the solution for three hours the gut-like material is washed first in dilute acid, then in distilled water for six hours, and finally in alcohol. The filament now in its crude state is wound on to drums and allowed to dry. After drying it is polished by passing through steel dies, cut into lengths, and mounted on carbon forms to produce the shape of the final filament.



Edison-Swan, Ltd

FIG. 5

SQUIRTING CARBON FILAMENT

The forms, with a number of filaments on, are placed in iron boxes and packed round with very dense pure graphite. The lids having been sealed on the boxes, and their contents are placed in the carbonizing furnace, and the temperature gradually raised to 1100° C. and kept so for twelve hours, after which the furnace is allowed to cool, the boxes are unpacked, and the filaments, now carbonized and brittle, are removed for inspection.

A batch of about forty filaments is sent forward through the factory and tested in lamps, which are run on time trial at 40 per cent. over their normal voltage, and if the results are satisfactory, the whole batch of filaments is placed into stock for use.

The length and diameter of each filament is accurately measured, the average of several measurements being taken in consequence of the filament being slightly eliptical in section. From the mechanical and electrical measurements the filaments are classified according to their resistance, and the batches so arranged are used for the different voltage lamps as required.

Mounting. The portion of the lamp through which the wires pass from the cap to the filament is termed the "seal," in consequence of the nature of the joint necessary to hold the vacuum of the bulb from leakage. It is very important that the seal should be as perfect as possible, for which reason the wire which connects the filament and passes through the glass must be of such a nature that it will adhere to the glass firmly. Platinum was originally used for this purpose, necessitating an added cost to the lamp, which has been overcome in recent years by the use of base metal alloys having the same coefficient of expansion as glass. While equally suitable for making the joint, the cost is only a fraction of that of platinum, which in a works making hundreds of thousands of lamps means a very considerable financial saving in the course of a year.

"Tital," a German invention, "Copper Clad," an alloy of iron and nickel similar to "Invar," upon which a film of copper is cemented to the core with silver solder, is an American product, while "Hyatite" is a platinum substitute wire placed on the market in England by the Edison-Swan Co.

With platinum seals it was necessary to use the smallest possible length of wire joining nickel-copper alloy wire on one end and copper on the other, the forming leading from the seal to the filament, the latter from the seal to the lamp cap. The same method is often used now with platinum substitute, the joint being made by welding, but in many lamps the alloy wire is continued from the filament to the cap in one length, the slight increased cost of which is balanced by the saving of labour.

In making the seal, the leading in wires (there are, of course, two to each lamp) are held in a parallel position in a short length of glass tube, one end of which is heated in a blow-pipe flame until quite soft, when two jaws are brought together either side of the molten tube, squeezing the wires into a bed of glass as described in a later section on lamp machinery.

The filament is joined to the projecting wires nearest the seal by one of two methods, viz., the deposited joint or paste joint.

The deposited joint is made by heating the junction of the filament and leading in wire in a hydrocarbon liquid, under which conditions heavy dense carbon is formed. A spiral or tube is formed at the extreme end of the leading in wire, so that the filament may be inserted to form a temporary joint before being properly fastened. Slightly above this joint, on the filament, a light clamp is fixed so that on passing current through the leads a short circuit is made cutting out the filament, so that on increasing the current the temporary joint becomes incandescent without heating the filament. When the junction, immersed in a mixture of Toluole or paraffin, or similar liquid, reaches a bright heat, the hydrocarbon is decomposed and forms on the heated portion a carbon deposit similar to gas coke, but very much more dense.

A paste joint is made by dropping or painting on to the mechanical joint a small quantity of graphite mixed with caramel. In fact, it is not essential to make the mechanical joint, as the filament may be held in the paste if of the right consistency until dry, being afterwards baked to positively harden the cement.

Flashing. Carbon exists, as is common knowledge, in several forms, and chemically the various conditions are known as allotropic modifications. That is to say that the elemental substance has the same chemical properties, but the physical characteristics are different. Lamp black, graphite and diamond are all carbon, the first and second being good electrical conductors, but the third is an insulator until broken down to one of the other conditions.

If a rod be made of fine lamp black, and a similar one with the same surface area and volume of graphite, they will require different amounts of electrical energy to bring them to equivalent temperatures. In the same way, a hard carbon filament will require less energy than a soft filament to bring it to a similar incandescence. A certain amount of heat will be lost by conduction through the supports, but most is lost by radiation, this loss depending largely upon the nature of the surface of the filament. If the heat be generated in the filament by the flow of current at a greater rate than it is radiated, the temperature will rise proportionately, but, on the other hand, if the radiation is greater the temperature will fall.

Carbon was selected amongst other reasons for its high refractoriness, but although remaining solid up to a temperature of nearly 4,000 C., it is found to be sufficiently volatile when heated in a vacuum at 1,800° C. to seriously affect the burning of a lamp when operated above such a temperature. Carbon has a very rapid evaporation several hundred degrees below its boiling point, in the same way that water will evaporate at a temperature considerably below its boiling point. In running a carbon filament lamp the object naturally—from the consumer's point of view at any rate—is to get the maximum amount of light for the minimum input of energy. The higher the temperature the more efficient is the illuminating quality of the lamp, but beyond a certain limit the rate of evaporation of the filament is such as to seriously affect the life of the lamp, in consequence of blackening of the bulb and the proportional decrease in the section of the filament which increases the resistance and directly reduces the current consumption, still further lowering its efficiency and life.

Keeping this fact in mind, together with the possibility of changing the physical condition of the carbon used, it was found that by forming a filament of the hard coke variety (referred to in the description of making the joint in hydrocarbon liquid) a lamp of the same efficiency but longer life could be made than with ordinary carbonized cellulose.

Steinmetz discusses the different modifications of carbon[1], and summarizes the properties thus—

(*a*) High resistance, negative temperature coefficient of electrical resistance, non-metallic character, high vapour tension at moderate temperature.

(*b*) Low resistance (within the range of metallic resistivities), positive temperature coefficient of resistance, metallic character, low vapour tension at high temperatures.

Originally the deposition of the hard variety on the softer base was for reducing unevenness and strengthening the filament, but in view of added advantages which the smoother metallic surface was found to give, it has been the custom, even since the introduction of the squirted cellulose process, to flash all filaments, so producing a more economical lamp.

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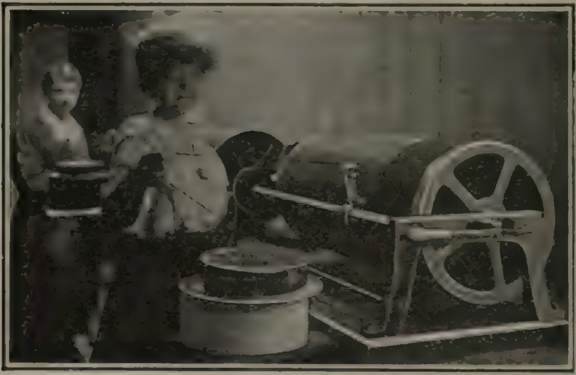
[1] *Radiation, Light and Illumination.* Steinmetz.

In mounting the filaments the object is to obtain a heavy deposit of carbon rapidly, for which reason the process is conducted in the liquid, but in coating the filament with a similar hydrocarbon vapour is used to obtain a more delicate deposit, which in view of the comparative slowness can be kept well under control.

Flashing is done in coal gas or benzine vapour. Similar highly volatile liquids rich in carbon may be used, but such as are suitable for jointing are of little use for flashing.

The apparatus used consists of a bell jar, made of glass, running vertically and balanced with a counter weight. When in use the jar fits on to a steel plate, making a reasonably vacuum tight joint by means of a rubber ring fitted on to the face of the plate. Through the centre of the plate is a tube, connecting, by means of a three-way metal cock to an exhaust pump, a chamber containing the hydrocarbon liquid, and the third opening to air. A stand with two terminals insulated from the apparatus, but carried through it is fastened to the plate. A filament to be flashed is fastened to the terminals, and the bell jar lowered to come in close contact with the base plate. The tap is placed in circuit with the exhaust pump, and a moment or two after is turned to allow the vapour from the benzine chamber to evaporate into the bell. The current is switched on, the filament glows, and the carbon is deposited on the surface of the filament. When the correct resistance is reached, the current is automatically switched off, enabling the operator to open the tap to air and raise the cover to remove the flashed filament.

It is highly important, in making the filaments, that the manufacturer should be able to turn out lamps of a particular candle-power with absolute accuracy. A variation of more than 3 or 4 per cent. on the voltage is not permissible in lamps of good quality, so that extreme care is necessary throughout, and particularly in the flashing process. A very slight error in calculation may mean a very serious loss, but, although to the uninitiated the process may appear complicated, in a well organized works it is extraordinary how the manufacture becomes a question of routine with the purely technical side almost forgotten.



Edison-Swan, Ltd.

FIG. 6

CARBON FILAMENT. POLISHING

Metallized Carbon. Although hardly coming within the scope of this chapter, a brief reference to metallized carbon filaments is necessary in view of the particular nature and advantages to be derived from this intermediate. Since it is produced by an exaggerated system of flashing, it may be described here before proceeding to consider the further processes.

The base filament, produced in the first instance by a means which need not be considered, has properties similar to a flashed filament such as has just been dealt with. By packing in graphite and heating to the vaporizing point of carbon in a resistance furnace, the filament changes its nature very considerably, becoming much more bright in appearance with an increase in density and strength, with many of the physical properties of a metal. In a lamp it gives increased efficiency and life, combined with very great strength. The cost of the metallizing renders the process uncommercial at present, but it is highly probable that an improved *drawn metal carbon filament*, possibly with advantages not yet thought of, will come on to the market within a short time, competing with the present efficient wire lamps.

Assembling. On receiving the bulbs, washed and dried from the glass blower, the first essential is to crack off the long neck, left from the moulding, to the desired length. For this purpose, a gas blow-pipe giving a large flame is used, so that the operator can heat rapidly and equally the portion to be broken off. When heated, but not sufficiently hot to soften the glass, the neck of the bulb is lightly pressed on a steel knife edge, usually kept cool by standing in a dish of water. The sudden chill cracks the glass in a perfectly even line round the whole of the circumference, and the rough end falls off into a bin at the side, while the trimmed bulb is passed on to be pierced. This is usually done in the centre of the spherical part opposite the neck.

a fine needle blow-pipe is brought close up to the glass until the portion is red hot and visibly soft. The neck end is then held tightly on an iron plate covered with a rubber disc and through the centre of which a small tube projects. As this operation is performed, compressed air is automatically blown through the tube in the plate, and unable to find immediate escape, selects the line of least resistance, which is by way of the soft glass produced by the needle burner. The action is very rapid, producing a small hole which is again heated in the blow-pipe, whilst held in a stand. Another length of glass tube, approximately the same diameter as the hole in the bulb and an inch or two in length is similarly heated. On bringing the two together the tube becomes welded into the bulb, and by a slight stretching movement the tube is constricted close up to the bulb, which facilitates rapid sealing off after exhausting, the tube being the means of connection with the pump for this purpose.

The pierced bulb is then held in a cup and the flashed mounted filament fixed in such a position that the flare or conical part of the mount comes in line with the edge of the bulb neck, the filament being, of course, inside the bulb. In the same horizontal plane a series of six or more blow-pipe jets are directed. Both filament and bulb are then rotated slowly at the same speed, the gas jets melting the glass equally all round. As the glass softens the flare begins to fall, while the bulb neck tends to close up, both edges coming in contact and fusing together. When the joint is made the flames are reduced, and the lamp ready for exhausting is removed to a warm place to anneal, otherwise a slight draught would crack the glass. The annealing is usually done by covering the neck portion of the bulb with a hot asbestos cone which protects the glass and allows slow cooling.

Exhaustion. Exhaustion differs considerably according to the type of lamp, but it has been customary during the past to pump carbon lamps by the schedule, which necessitates heating the filament during the process.

Into the piecing is placed a small dab of moist red phosphorus, the lamp being then sealed to the fork on the pump bench, connecting with the exhaust system over a tube of phosphoric acid to prevent the return of moisture to the bulb. Sealing is accomplished in a similar way to the method of piecing already described. The fork is not necessarily restricted to one lamp, as five or six may be connected in exactly the same way on to the main pump connection. Opinions differ as to the relative merits of "single" and "multiple" exhaust, the latter usually proving to have the greater advantages, provided leaky joints are not encountered, which often necessitates considerable waste of time in finding the trouble, holding up the pumping of the remainder of the set in the meantime.

With multiple or single pumping the routine is practically the same. The rough pump is placed in connection with the lamps, rapidly removing the greater portion of the air in the lamp or lamps. This takes place within a few seconds of turning on the pump, so that immediately after the operator can draw down over the lamps an asbestos oven, heated by gas or electricity, which raises the glass of the lamp to about 300° C. The effect of this is to drive off water vapour and other impurities which have condensed on the surface. The higher the temperature the better is the final lamp; but in consequence of the vacuum the walls of the bulbs have to withstand an external pressure of some 14 lb. to the square inch (atmospheric pressure), so that a temperature approaching the softening point cannot be relied upon. The fine exhaust pump is then put in action, and the lamps allowed to run a few minutes while another fork is being prepared. On returning to the first set, a small current is passed through the lamps, bringing the filament to a dull red heat, observation being made through a mica window in the asbestos oven. This sends the mercury gauge down as the result of expulsion of occluded gases in the filament, and time must be allowed for the pump to pull the vacuum up to barometric height again before going further. The heating of the filament is gradually increased to remove all possible volatile products, while

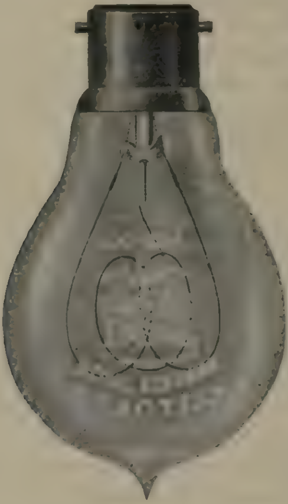


FIG. 7

CARBON FILAMENT LAMP

being still pumped, at an efficiency much higher than would be the case in normal use.

At this stage the bead of red phosphorus is brought into action by gently warming with a blow-pipe that portion of the piercing containing it. Yellow phosphorus is formed by the heating and vaporizes into the lamp, combining with any residual impurity such as oxygen. A rather beautiful effect known as " blueing " takes place during the driving in of the phosphorus, a misty blue vapour being formed, which disappears upon flashing the lamp on and off, indicating the clean-up of the lamp.

The vacuum of the system is continually tested either with a McLeod gauge or high tension transformer, which gives a glow discharge if the vacuum is bad. When pumping is considered satisfactory, the portion of the piercing which was described as being constricted is gently heated with a small flame, then rapidly fused, the soft glass being sucked in by the vacuum as the lamp is drawn away. The somewhat rough " pip " is then trimmed and the lamp allowed to cool.

Other substances are sometimes used for " cleaning up," and other slight variations in routine are adopted, but the above description gives a fairly accurate account of the method of manufacture of the ordinary carbon filament lamp, the present type of which is rapidly becoming obsolete.

CHAPTER III

THE METAL FILAMENT LAMP

ALTHOUGH the requirements in an incandescent lamp are numerous and exacting, it becomes an impossibility to make a thoroughly satisfactory commercial article without a reliable filament, which is, after all, the most essential part.

In 1914, in America alone, 240,000,000 lamps (apart from motor and miniature lamps for pocket batteries) were manufactured, and of the world's output more than nine-tenths are made with the tungsten filament.

Considerable space has therefore been devoted to what is one of the most interesting and at the same time most important and difficult processes in connection with lamp-making. An inferior filament gives rise to endless complications and losses in the later processes of manufacture, while the possibility of such lamps getting on to the market may cause damage to the maker's good name by a not over-considerate public who, naturally, judge goods in comparison with the best product.

Tungsten, fortunately, occurs very abundantly, and although large quantities of the metal are made for use in the manufacture of high speed steel, the same quality is not suitable for making wire, in consequence of the many impurities which it contains and its physical condition, both of which render it useless for rolling or swaging.

The lump metal in this form is usually prepared by reduction and fusion in the electric furnace. The high melting point of tungsten, which property renders it so useful for lamps, has, in the case of steel, to be reduced by mixing a certain quantity of iron, so that the ferro alloy so produced will fuse when added to the liquid steel before casting. Therefore in commerce the larger proportion of tungsten produced is in the form of alloys, and not very often in even a reasonably pure state which might be used as a base to work from, for making filaments.

Scheelite and wolframite are the two principal ores of tungsten, the former being preferable to work, as it has the lowest percentage of objectionable impurities. Either ore may be used, but in view of the comparatively large number of filaments from a relatively small quantity of tungsten, sodium tungstate, obtained by roasting the ore with soda carbonate, is often used as the initial product.

If scheelite is selected for use, it is very necessary to grind it to fine powder, or the yield will be low. The after treatment may vary in detail slightly, according to the manufactures, but all methods aim at producing a similar result, for which reason several conditions are necessary.

Preparation of Oxide. After chemical analysis in the laboratory, which indicates the quantity of reagents necessary for treatment, the ore, previously reduced to a fine powder, is introduced into an acid-proof vessel, together with a calculated quantity of hydrochloric acid.

The vessel may be of porcelain, glass, metal or any material which may be heated without being attacked by the acid. A close-fitting cover is provided through which passes what is known as a reflux condenser, an apparatus so designed that liquid condensed therein is returned to the original container instead of to another vessel. By such means, when the ore is heated with hydrochloric acid, instead of quantities of fumes being evolved, polluting the atmosphere of the room, and also entailing considerable loss of material, the acid is recovered, coming in contact with the mineral again and further helping decomposition.

A small quantity of manganese dioxide is often mixed with the " batch," which generates chlorine, so increasing the activity of the hydrochloric acid.

After a period of digestion from four hours upward, according to the bulk of material, the ore will have changed from a grey mineral to a bright yellow oxide of tungsten, which is separated from the remaining liquid, first by decantation, then by filtering in a vacuum funnel.

The viscous mass remaining is further heated to dryness to render certain impurities less soluble in the ammonia solution with which it is further treated. Ammonium tungstate so formed is a colourless solution when pure, but to remove iron and silica, which are precipitated by the reaction, a second filtering is necessary, after which purification is continued to any desired stage by re-crystallizing.

When hydrochloric acid is added to ammonium tungstate the yellow oxide (just as obtained from the ore) is again thrown down as a pure substance, but a chemical difficulty is experienced which it is necessary to control to avoid trouble in the later working.

If the acid is added too rapidly to the tungstate solution, a white precipitate of tungstic acid will be produced, and although with boiling a large proportion of this acid will be oxidized to the required yellow condition, a considerable quantity of " colloidal " tungsten will be formed, which it will be impossible to remove without baking down to a dry state.

Not only does this formation cause trouble in filtering and washing, owing to clogging of the filter pores, but it has a harmful effect on the physical properties of the metal which are developed in the swaging operations.

To prevent the formation of colloidal tungstic acid in the solution, instead of adding the hydrochloric acid to the ammonium tungstate, the reverse treatment is carried out, giving, when controlled properly a heavy granular oxide which can be easily filtered and washed.

The precautions taken in this process are to add drop by drop a hot strong solution of ammonium tungstate to a rapidly boiling solution of hydrochloric acid, maintained in a condition of violent bubbling by passing a stream of clean air through, so avoiding the settling of the tungsten oxide to the bottom of the vessel.

Different makers vary this method according to individual opinion. The ammonium tungstate, for example, may be heated to remove ammonium salts, leaving a green yellow oxide, of the same chemical composition as that produced by the precipitation method, or the tungstate and hydrochloric acid may be baked together as in the original treatment of the ore.

The object of all these variations is to obtain a pure granular oxide free from fine dust as far as possible.

With a view to obtaining a regular granular product, the General Electric Co. of America fire the pure dry oxide in a clay crucible, which process is claimed to drive some of the crucible material into the tungsten oxide, rendering the eventual filament more immune from "off-set." Unless some such treatment is applied, the wire, when heated to high temperature in the lamp, tends to return to the crystalline form, in which condition it is extremely sensitive to mechanical shock, breaking across the lines of cleavage, of the large crystals which are produced.

It is more customary now to work with pure material and add measured quantities of the retarding chemicals, usually silica, alumina or thoria.

As an average example of the treatment, the dried pure oxide is mixed with thorium nitrate solution in such quantities that the thoria ($Th O_2$) will be equal to 0·75 per cent. in the tungsten oxide. More water is added if necessary to form a thin paste of the mass, which is mixed very thoroughly in a paint mill, and then dried and sifted through fine mesh silk, in which condition it is ready for the reducing process by which it is converted into powdered metal.

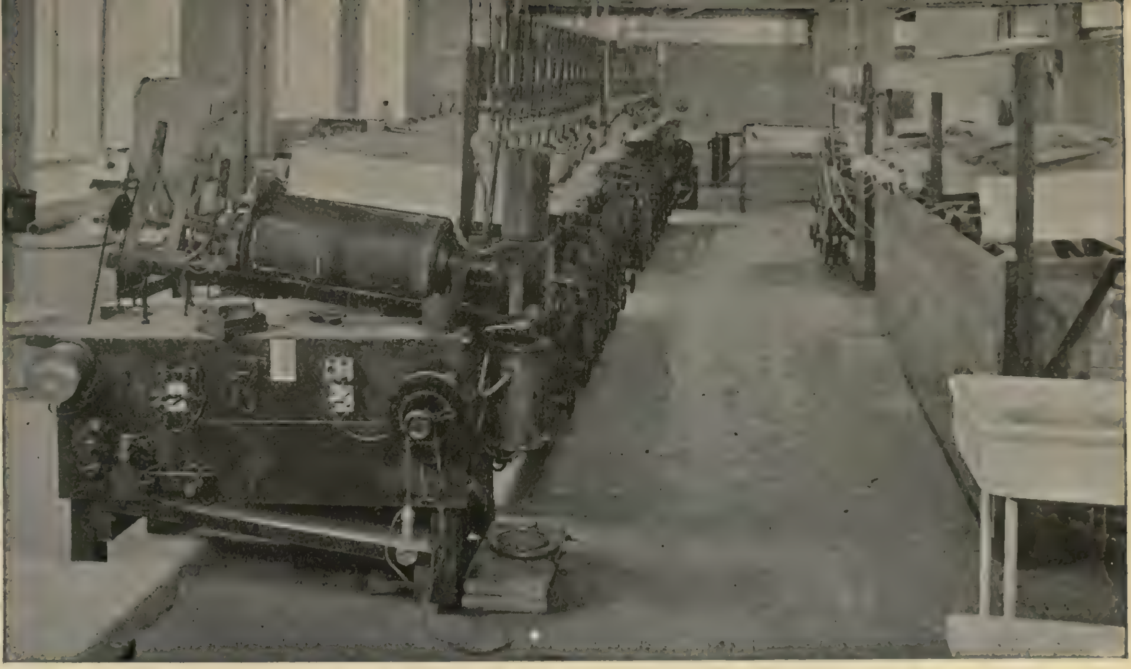
Preparation of Metal. When clean, dry hydrogen is passed over heated oxide of tungsten, the oxygen of the tungsten combines with the gas to form water, leaving tungsten in a more or less reduced state, according to the temperature and time of operation. The result may be a blue, brown, black or grey powder. It may be extremely fine and amorphous, or dense and crystalline. The most suitable tungsten for drawing into wire is obtained from the grey, dense powder, which must not, however, be crystalline.

Great care is necessary to so reduce the yellow oxide in order to obtain a full and satisfactory yield of the metal which will work well in the swaging and drawing operations.

The hydrogen must be pure and carefully dried by passing through caustic soda, sulphuric acid and phosphorus pentoxide ; the furnace must be easily under control and perfectly evenly heated.

The furnaces adopted for use are usually of the tube type, heated by gas or electricity, the oxide for reduction being contained in boats or smaller tubes inserted in the furnace tube.

Reduction is carried out over a range up to 1,100° C.,



By permission of FIG. 8 *H.M Stationery Office.*

TUNGSTEN REDUCTION FURNACES AS USED IN AMERICA with a full flow of hydrogen to remove the water-vapour formed, otherwise the metal would become highly crystalline and useless.

The grey powder obtained, commonly termed tungsten metal, but containing about half per cent. of oxide, should pass what is known as the "tap test," which consists in weighing ten grams into a graduated cylinder and tapping until a permanent level is obtained, which should measure about two cubic centimetres, if correct, for pressing and sintering.

Forming. The tungsten powder is pressed dry into rods ten to fourteen inches long and about one-quarter of an inch square or in diameter, according as the mould may be square or round. Pressure is applied on the side, and not from the ends which would cause an uneven grain and give rise to cracks. A high pressure is applied and released on all sides simultaneously to obtain an even strong rod which (handled with sufficient care) may be transferred to a tube furnace with hydrogen passing through for the purpose of hardening the rather fragile stick of metal.

After baking at a temperature of 1,000° C. for thirty to forty minutes, the rod has considerable strength, and may be handled without any fear of breaking, in which condition it is clamped into the sintering bell, one clamp being fixed, and the other, floating on mercury, surrounded by a water jacket, to allow for contraction which takes place while the rod is being brought to incandescence. The bell, also, is water-cooled and sealed with mercury, so that even at a temperature of 2,700° C. to 2,800° C., which the rod reaches during sintering, there is little chance of over-heating, which, with the chamber full of hydrogen, would cause serious accidents.

The object of always using hydrogen when heating tungsten to these high temperatures is to avoid oxidation, which would rapidly take place with ruinous results if oxygen gained access.

By judicious handling in the sintering operation, slight errors in the reduction can be corrected without affecting the routine to any great extent, and the man who can nurse a poor metal through the sintering and swaging is a very valuable acquisition to any firm who has the good fortune to employ him.

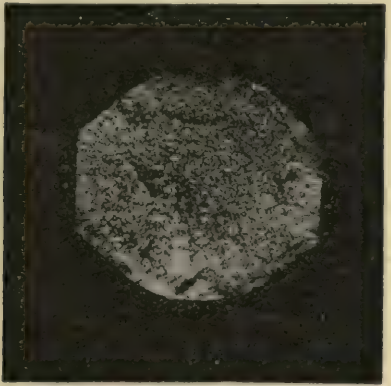


Fig. 9

SECTION OF TUNGSTEN ROD
Enlarged × 2

The fracture of a sintered ingot should be a bright close-grained structure without unduly large crystals.

A very definitely crystalline product will cause trouble in the swaging, owing to the extremely high heat necessary to counteract the effect of mechanical working, without which heat the rods will break. Provided the heavy swaging operations can be applied without fracturing the bar, the later drawing processes will be considerably easier, with less likelihood of splitting in the very fine wires.

On the other hand, a smooth-grained ingot with a somewhat satin-like sheen will render the earlier processes of hammering simpler, without having to anneal at high temperatures before each pass through the swaging dies, but in the wire drawing, and particularly in the finer stages, considerable losses due to split wire will occur if care is not taken to apply the necessary heat.

The first swaging at a temperature of 1,700° C. is conducted in a special machine with dies of high speed steel, made in two sections so that the centre alternately opens and closes while the die sections rotate at a high speed.

A tube furnace by the side of the swaging machine holds the ingots, and the operator, gripping one end in a pair of specially constructed tongs, withdraws and inserts the tungsten bar between the swaging dies. As the hammering only takes effect a little beyond the centre of the rod, the same process is repeated for treating the opposite end.

The first passes are at a high temperature, with a very small reduction each time, until the rod, originally about 5 or 6 mm., is reduced to a round rod, considerably elongated and 2 to 2·5 mm. in diameter.

The temperature is then reduced, and the rod, which is now too long for manipulation with tongs, is fed through a tube furnace direct into a smaller swaging machine and discharged at the opposite side into a trough, which process is repeated down to a size of 0·75 to 1 mm.

At this stage the temperature is considerably reduced to within the region of 1,000° C., the wire being small enough in section and sufficiently flexible to be wound on spools of about 12 in. diameter.

Further reductions are made by hot drawing through diamond dies, the sectional area being reduced approximately 10 per cent. at each pass. When approaching the desired size of wire, heating is abandoned to give additional strength and surface to the finished product. The surface of the filament has very important bearing on the life of the lamp, a point dealt with in a later chapter.

Assembling. Assembling of tungsten lamps is very similar to that of carbon lamps, except that the parts are more numerous in consequence of the length of filament used, the necessity of this long filament requiring a further operation to give a zig-zag shape to the wire, which makes the mounting on the stem more simple. The shape is set on the wire while hot in an atmosphere of forming gas, either by winding on to the "form" while making the wire dull red by passing current through or by placing the form with the wire ready mounted into a chamber which is heated. The latter method has the advantage of reducing labour and producing perfectly uniform treatment, not permitting the possibility of personal error. When the wire is to be gettered (see page 40), the forming must, of course, come before the gettering or the deposit will be given off. The forming by the above methods also has the advantage of cleaning at the same time, an operation necessarily done separately if the forming is done cold after gettering.

The stem of the lamp consists of the already described vacuum seal with an addition glass rod fused in between the wires in a vertical position. This cane of glass has two buttons formed on it, one at the extreme end, the other a short distance from the seal. Into these buttons, while heated in the blow-pipe, are fixed short fine wires usually of molybdenum, or similar refractory metal, to support the filament. The extreme end of the leading-in wire is bent round to form a slot to take the filament, one end of which is inserted and the slot closed with a pair of pincers. The zig-zag wire is then looped, first over a top hook, then down to the other end of the stem round a bottom hook, and so forth until the other leading-in wire is reached, into which the filament is again clamped and cut off, the mounted stem being now ready for sealing in. Before the advent of the dark exhaust method it was usual for the wire to have a further flashing to clear it from surface dirt accumulated during handling, but with the newer methods the

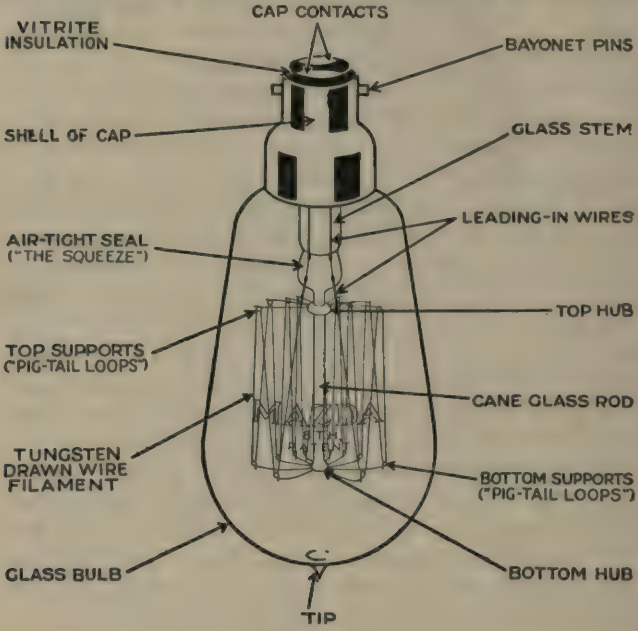


FIG. 10

TUNGSTEN FILAMENT LAMP

stem, if not already gettered, is dipped or sprayed and then sealed into the bulb, phosphorus in the piecing, of course, only being necessary in such cases where ordinary exhaust and lighting of the filament is used.

Chemical Exhaust. The great developments in the lamp industry have been largely dependent upon the degree of research in the various laboratories of the big lamp corporations, in consequence of the growing demand for the improved drawn wire lamp.

For the production of millions of lamps it is possible but not economical to depend entirely upon the perfection and rapidity of modern exhaust pumps, and even early in the days of the carbon filament lamp the benefit of introducing chemical methods in a minor degree was thoroughly realized.

The introduction of red phosphorus into almost every type of lamp made for cleaning up on the pumps is universal, it being used alone or with other components according to circumstances.

In exhausting a lamp the primary object is to remove impurities such as oxygen and water-vapour, which have ruinous effect on the filament. Of the two, the latter is more serious, as theoretically, pure dry oxygen in minute quantities would have no observable effect on the filament, but in the case of traces of moisture a cycle reaction takes place, which causes blackening of the bulb and rapid burn outs—the reaction being due to the splitting up of hydrogen and oxygen; if one of the gases be fixed or absorbed, the other will have very little influence.

Earlier methods of washing out the lamp with an inert gas during pumping proved satisfactory to some extent, but increased the time and decreased output, while the result was not such as to merit a change from the ordinary methods. The alternative, however, of introducing a substance which would yield extremely minute pressures of gas, chiefly the halogeus, which reacting with the black tungsten deposit on the bulb would form a thin film of oxide not observable under ordinary conditions, proved of considerable success.

Substances of this nature are termed "getters" or "fillers," according to the nature of their purpose, taking up or "getting" some impurity in the lamp or (partially) "filling" the rarefied atmosphere in the bulb with an element or compound for a certain chemical reaction. The object of the getter is for a rapid clean up in, or after exhaust, the filler being introduced to increase the useful life of the lamp.

The use of either or both will obviously shorten the pumping, inasmuch as the degree of vacuum need not necessarily be so perfect.

Phosphorus is a typical example of getter, while sodium fluoride, thallium chloride, potassium iodide, are fillers of commercial importance, usually being placed in the lamp in a position on the stem surrounded by the filaments.

In placing the chemical on the stem, certain precautions are necessary to avoid an excess of material being over-heated, which would be more harmful than its entire absence. Too great a quantity will produce a vivid iridescent effect on the bulb, while too small a quantity, or the fact of being subject to insufficient heat, will render its value useless.

By preparing a varnish in which is suspended or dissolved the necessary chemical, it is possible to introduce into the lamp a regular quantity of material rapidly and economically without affecting its normal appearance, the quantity being much less and the effect more definite by using such a preparation.

The application is usually made to the filament as received from the wire drawer, after cleaning in forming gas (hydrogen and nitrogen), in which case it is necessary to recoat the treated wire with a further protecting varnish to avoid injury to the delicate surface during the numerous handlings which it must go through. The filament may also be sprayed on with an atomizer, after mounting and immediately before sealing in.

Now a particular advantage of this method of using gettered wire is that the phosphorus may be incorporated with the other material instead of necessitating a separate operation, and the lamp so assembled can be exhausted without the filament being heated. Heat for driving off gases condensed on the interior surface of the glass is, of course, necessary, but the trouble of flashing the lamps on the pumps to " remove the blue " is entirely removed.

An example of the method of application and formula used in heating filaments, that published by the General Electric Co. of America (BP. 11,544/15) may be referred to as typically modern.

The wire is run in a groove of a wheel which dips into a vessel containing the solution with which the wire is to be coated. The coated wire is then passed through a protective coating mixture to provide the covering for the coated filament. By this method a uniform and evenly distributed coating of the active material is obtained with an equally similar protective surface.

Substances most suitable for use in a lamp in accordance with the invention are inorganic halogen compounds, such as iron fluoride, manganese fluoride, and double fluorides. The substances are dissolved in suitable liquid solvents or applied in suspension.

The double fluoride of sodium and iron, for example, may be made into a paste with a liquid, such as alcohol. A solution of nitrocellulose is added, in the proportion of three grains of pyroxylin in 100 cc. amylacetate, the proportion of nitrocellulose solution to the chemical paste being approximately one-half of the former to one part of the latter by volume. The viscosity, which is important in consequence of the quantity of material to be taken on to the surface of the wire, is such that at 23° C., 100 cc. will pass through a standard oil pipette in 110 to 130 seconds.

Research work is now largely directed to the possibilities of chemical exhaust, lamps having actually been made without the use of mechanical pumping and giving excellent results on life and efficiency tests.

With the present standard methods of "dark exhaust" (the term applied to exhausting without flashing the filament) the wire is gettered before or after mounting, according to the nature of the chemical used. The assembled lamps are connected to the fork of the pump by short lengths of high-pressure rubber tube, insertion being rendered more easy by the application of a little pure castor oil. This method is more rapid and equally efficient as sealing on with a blow-pipe. Preliminary pumping is then begun in the same way as described in the treatment of the carbon lamps, heat being applied to the bulb but not to the filament. The degree of remaining pressure is tested from time to time with the McLeod gauge or coil until satisfactory; the lamps are then sealed off with the blow-pipe and placed on a frame, where a large number of lamps are lighted up with about 20 per cent. excess voltage in one minute. The phosphorus is driven off to clean up the evolved gases from the filament, and the filler and getter come into operation.

No more than one or two minutes' supply of current is used on the filament during the entire process, the lamps afterward being ready for measurement and capping.

CHAPTER IV

GAS FILLED LAMPS

WITH the metal filament lamp a consumption of 1·25 watts of power for every candle-power is considered standard, and all lamps of this type are made to such specification. As with the carbon lamp, a higher efficiency may be obtained by running the filament at an increased temperature, but there is a practical limit to the point at which efficiency in both light and life are balanced. If the filament could be run at a temperature of 3,540° absolute (melting point of tungsten) the lamp would be six times as efficient in light, but the life would be reduced from 1,000 hours to about one minute.

The life of a lamp does not necessarily mean the number of hours before burning out. A drop of 20 per cent. in candle-power is considered the termination of the lamp's usefulness, and, although it may then be more efficient than the old carbon filament, the cost of renewal after such a period is more than balanced by the saving in current. It is the object of every manufacturer to produce such lamps, and reference has already been made to "camouflage" methods which have been adopted to make the black deposit invisible, by the introduction of various chemicals, thereby producing a good lamp at a cheaper cost, with the minimum blackening.

But it was not considered satisfactory by the lamp industry that a substance with a high melting point like tungsten should be run at such a low temperature, for the higher the temperature the greater the light emitted per unit of surface area, it being remembered that even with the gas filled lamp nearly 90 per cent. of the energy is wasted. A truly efficient lamp would only consume about 0·06 watts per candle power.

Research was conducted by the General Electric Co. of America in an endeavour to find the true cause of the blackening, with a view to overcoming it, and thereby making it commercial to run the filament at a higher temperature with the obvious advantages. Langmuir and his collaborators[1] found that with a poorly exhausted lamp the residual gases were negligible as far as blackening was concerned, but even slight traces of water-vapour produced discolouration of the bulb, due to the cycle reaction with the incandescent filament referred to previously. Even under ideal conditions of exhaust, where precautions were taken to eliminate water-vapour, blackening still took place, which served to prove that the effect was additionally due to direct evaporation of the tungsten.

By introducing an inert dry gas into the lamp, it was found that as the pressure was increased the evaporation of the tungsten was reduced in a direct ratio, but, although the emissivity per unit of surface area was in proportion to the eleventh power of absolute temperature, the input in energy expended was greater in proportion in consequence of the heat conduction of the gas.

With hydrogen it was found that the heat conductivity at high temperatures was abnormally great, much greater than would be expected from a comparison of its heat conductivity with other gases, a peculiarity due to the gas becoming dissociated into atoms.

Nitrogen was found to have little conducting effect, but while inert toward the filament, nitrides of tungsten were found with the metallic vapour which deposited as a light brown film on the cool surface of the bulb, but lamps with filaments of large diameter were satisfactorily made, which ran at an efficiency close to the melting point of tungsten, with the evaporation considerably less than under similar conditions in vacuum.

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[1] Langmuir, A.I.E.E., 34, 860 (1912).

Argon as a gas of absolute inertness under all conditions, and with lower heat conductivity than nitrogen, was suggested, and gave very excellent results, but the difficulty of obtaining a rare and consequently expensive gas was a drawback for commercial development.

The increased demand for oxygen in acetylene welding operations resulted in the manufacture of liquid air on a very large scale, and in view of the possible demand for oxygen in large quantities, Claude and Linde designed improvements by which the gas could be fractionally distilled, compressed into cylinders, and sold at a very cheap rate, practically free from nitrogen and other impurities.

It has already been explained that although the blackening was reduced even at higher temperatures, it was necessary to use more power in producing a given luminosity except in the case of large diameter wires. In a lamp made with a 10 mil. filament, running at a temperature which, if in vacuum, would be equal to a consumption of 0·37 watts per candle, the difference being due to connection and heat losses, therefore if two wires, having the same total surface area but of different diameters, are raised to equal temperatures in vacuum, the total emissivity will be equal, but if the same condition be produced in argon or other inert atmosphere, the thin wire will lose considerably more heat in proportion to the comparative diameter of the other filament.

To reduce the loss by heat, therefore, a rod or tube might be used, but the resistance necessary for high voltage lamps would be such that only very large units could be made. But by coiling the wire into a tight spring or spiral, the same condensed effect was found possible with a normal amperage.

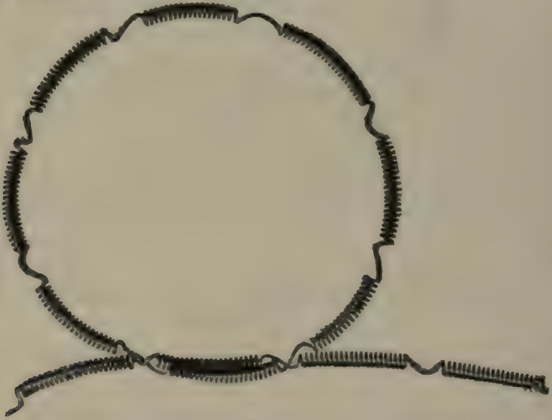

FIG. 11
HALF WATT FILAMENT

By arranging the spiralized filament in a horizontal position, it is further possible to concentrate any deposit, principally of tungsten nitride, on the neck, instead of all over as in the ordinary filament lamp, and each in such position the effect is negligible except after long running.

By observing the principles briefly outlined, it has been found possible to construct lamps on a commercial basis with a life of 2,000 hours running at half-watt per candle consumption.

The larger the unit the more efficient is the lamp in both life and consumption, but small units are now made which at 0·6 watts per candle have an average life of over 1,000 hours.

Filament. The filament of the gas-filled lamp is, as already mentioned, coiled into a spiral to balance the heat losses experienced when using a straight filament, a necessary condition to avoid the heavy current which would otherwise be required.

It is, of course, impossible to wind fine filaments into a helix by hand, as it is extremely important to make the spiral with a perfectly regular pitch. This operation is performed on specially designed machines (Chapter V), which, while giving a regular result, make up the filaments at enormous speed.

The wire is wound (on the machine) on a steel or bronze mandril, which is of such nature that while being capable of being held in a taut position will not have any tendency to stretch, causing in consequence a reduction in the diameter which would be equally produced in the winding of the spiral.

To obtain the advantages associated with a large diameter coil, it would be preferable to use a large diameter mandril, but at a temperature of 2800° C. even tungsten becomes a soft material, and the weight of the wire tends to pull out the spiralizing to a serious extent, the effect of which reduces the efficiency of the lamp as a result of more rapid head radiation, which it is the object of the coiling to prevent. In general practice, it is assumed that the mandril should be approximately the same diameter as the filament used; a smaller size would cause difficulties in the actual winding, due to breaking of the tungsten.

With the ordinary filament lamp any difference in the diameter of the wire causes a very serious effect.

The thin portion heats more readily, and immediately shoots off tungsten vapour, thereby becoming thinner and hotter, so that within a short space of time it burns through owing to the intense heat which it attains. In the gas-filled lamp the reverse effect is produced. The thin portion of the filament will tend to overheat, and, as a result have less mechanical strength, causing the spiral to droop; the heat losses become greater as the temperature is reduced, preventing further volatilization. But if the drooping, due to this or any other cause, becomes so excessive, the temperature generally is reduced, and the emission of light from the surface equally so.

Many of the so-called "half-watt" lamps on the market now will, on first testing, appear efficient, but after a hundred hours in use the consumption of current will actually be more than with the ordinary type of lamp, such variation always being indicated by acute drooping of the filament.

For these reasons the domestic user always obtains the best value in using gas-filled lamps which burn without undue sagging of the filament, combined with only moderate darkening of the bulb.

In addition to the physical and chemical properties of the filament, the design of the lamp, and particularly the bulb, play an important part in effecting efficient running.

With the vacuum lamp, provided the bulb is sufficiently large to take the stem and filament, it may be of almost any convenient shape, but with gas-filled lamps the energy radiated from the filament is carried in a vertical position by the movement or "convection currents" set up by the gas. If, therefore, the bulb is not properly designed, and any portion becomes excessively heated, the water-vapour absorbed by the surface of the glass will be released and carried round with the stream of hot gas through the filament and dissociated as previously described, blackening the bulb and reducing the efficiency of the light.

The difficulty may be overcome by enclosing the filament in a very large bulb, and so providing a much more considerable area for the volatilized tungsten to deposit upon, but if the filament is arranged lower and a long neck provided, the effect is equally satisfactory, due to the gases, in having to move further, not overheating the glass. In cases where the lamp is used in reverse way, or in a horizontal position, the advantage of the larger neck is lost.

It is also possible to reduce the difficulties due to the connection currents by using high resistance glass, which allows a higher temperature being used during exhausting, without softening, but driving off an additional quantity of water-vapour. Silica could be used, in which case a red heat could be applied to the bulb, but the increase in cost would not be compensated for by the advantage gained.

In the larger lamps taking a large current the heat from the filament is very considerable, so that special precautions are necessary to avoid the hot gas coming in contact with the seal. It is absolutely necessary to protect the seal from cracks which might arise from the alternate heating and cooling when switching the current on and off, as the slightest leakage would cause rapid burning out as a result of even the minutest trace of oxygen. To deflect the heat somewhat, small discs of mica are fixed on to the leads and close up to the neck, a precaution which is not usually taken in the smaller units where the heat is not so great in proportion; but with the large units the heat in the immediate vicinity of the filament is so intense that if the filament was supported by nickel, it would vaporize and rapidly blacken the lamp, so that tungsten supports have to be used and as tungsten will not seal in to ordinary lead glass, a stud or button of special glass has to be fused to the stem, which will hold the tungsten supports firmly without cracking out.

Very careful calculation is required in deciding the size of the leads and all the internal parts, as the loss due to conduction and, therefore, lowering of the temperature of the filament would make a very considerable difference to the efficiency of the lamp, where the object is to use as much of the current as possible in maintaining the incandescence of the filament, and not in heating the other unfortunately necessary parts.

The idea of the non-technical man that the gas-filled lamp is not an exhausted lamp is very misplaced, for, unless they are made extraordinarily good, vacuum lamps before filling with the gas, a very short life can be predicted.

As preliminaries, clean bulbs, stems, filaments and wires must be used, and pumps giving a high degree of exhaust in a short period are equally important. Joints must be very carefully made, because the circuit one is not only dealing with evacuated tubes, but also with large quantities of expensively prepared gas, which may easily be the cause of many lamps being spoiled should a dirty tap or faulty joint be used for the gas supply.

The lamp is connected to the pump in the same way as the ordinary type, and the exhaust pump turned on before the canister is lowered. This is to prevent the air in the lamp oxidizing the wires by sudden heating due to the canister, which is avoided by reversing the operation to obtain a partial vacuum before heating.

The temperature at which exhausting takes place is of considerable importance, as the water-vapour on the interior surfaces will only be expelled in proportion to the degree of heat and exhaust. One without the other is of little use, and conditions suitable for vacuum lamps would not be so suitable for gas-filled lamps, as by the introductions of the gas the bulb becomes heated to a higher temperature and releases the moisture, as has been mentioned in dealing with the design of bulb.

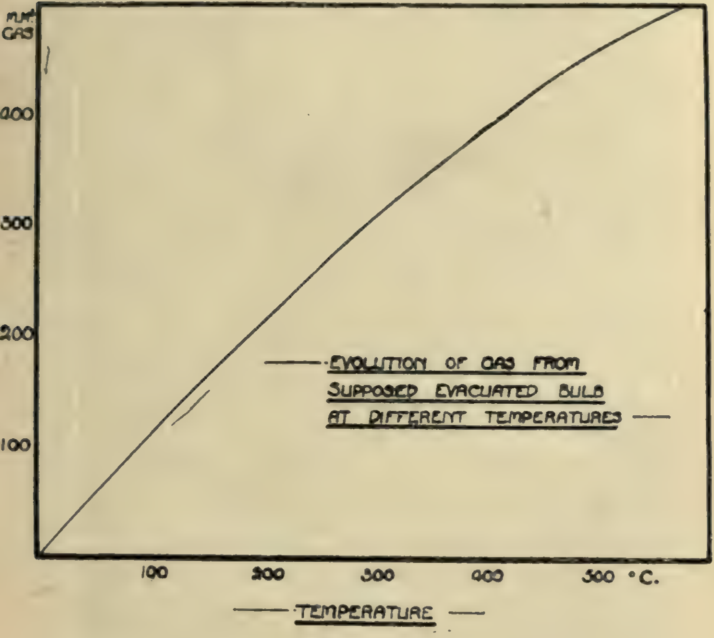

Fig. 12

CURVE SHOWING EVOLUTION OF GAS FROM BULB DURING EXHAUSTION

A diagram is given illustrating the effect of heat on the bulb, and shows the increase in the evolution of gas as the temperature is raised. We see that at 200° C. nearly 207 cu. mm. of gas are given off, which is increased to 324 cu. mm.—that is to say, a further quantity of 117 cu. mm. at 350° C., and by again heating to 500° C. a total of 495 cu. mm. gas is obtained. So that in pumping, if the temperature was 200° C. when the lamp was in use, there would still be a considerable quantity of gas in the bulb as impurity, which would be released if the temperature, due to radiation and conduction, over-reached 200° C. In practice it is not possible to work as high as 500° C., as the strength of the bulb under such conditions would not be sufficient to resist the external pressure.

As with vacuum and carbon lamps, phosphorus is introduced by one means or another to give a final clean up when the lamp is first run.

When the exhaust is sufficiently good, being tested either by the McLeod gauge or coil, the pump is turned off, and the gas allowed to flow into the lamp, over phosphorus pentoxide, to remove any slight moisture which may have accumulated from the surface of the supply pipes. The pressure in the lamp when cold is such that when running it is just one atmosphere.

Some little detail is necessary regarding the preparation of the nitrogen and argon for filling the lamps, for the manufacture of either is a most highly-developed physical science.

Argon is an inert dense gas found dissolved in mineral waters and to an extent of a little under 1 per cent. in the atmosphere. The quantity found in the air of London, Paris, Berlin, and on the top of Mount Blanc was[1] 0·9315, 0·9319, 0·9323, 0·9327 per cent. respectively.

[1] Moissan. Comptes. rend. 1903, 600–606, and Cavendish, Chem. Soc. J. LXXI, 1897, p. 181.

So far, all attempts to make it combine with other elements have failed. Fischer and Iliovici[1] made experiments in this direction, and sparked liquid argon between cadmium electrodes, but the yellow substance obtained and first thought to be a new compound, turned out to be due to a small trace of nitrogen having formed cadmium nitride. This property is naturally an advantage in the case of lamps where attack of the filament must be reduced to the lowest limit.

The three methods, variations upon which are numerous, of obtaining argon are (1) sparking oxygen and air, removing the nitric acid so formed; method (2) as described by Fischer and Ringe, consists in passing purified air over heated calcium carbide[2], thus absorbing both the oxygen (with formation of lime, carbon oxides, and possibly carbon) and the nitrogen ($CaC_2 + N_2 = NC.NCa + C$), a reaction which the inventors of this method find to be irreversible, within the limits of temperature they used, the gas obtained on a first passage over the heated carbide being circulated over it again and again till no further absorption occurs. The arrangement of the apparatus will be understood from the diagram. (Fig. 13.)

An iron tube holding about seven kilos of carbide, with water-jacketed ends, was heated in a furnace, not shown in the figure, to a temperature of 800° C., after filling with a mixture of 90 per cent. of calcium carbide and 10 per cent. of dry calcium chloride, and all evolved gases taken away by a water-pump. Connection was then made to the apparatus as shown, and the whole apparatus evacuated by the water-pump connected at 1. Cocks 1, *d* and *f* were now closed, *g* opened, so that air could stream through the gas-meter and the vessel

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[1] Ber. 1908, 3,802–3,810.

[2] Ber. 1908, 2,017–2,030.

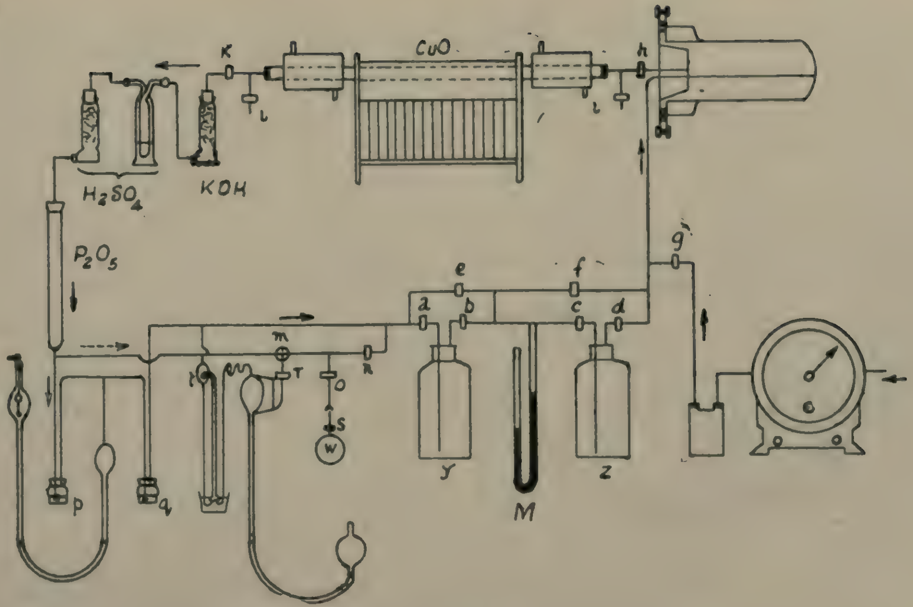

Fig. 13
DIAGRAM OF METHOD FOR PREPARATION OF ARGON

for absorbing moisture and carbon dioxide into the carbide vessel, and *h* very slightly opened so as to allow a very slow passage of air through the carbide vessel. This was allowed to go on till the whole apparatus was full of gas at atmospheric pressure, the gas on its way from the carbide to the gas holders passing over heated copper oxide and through the absorbing tubes to remove any carbon monoxide, hydrogen, or hydrocarbons, as well as all the carbon dioxide produced. At this stage the cock *g* was closed, *d* opened, *h* fully opened, and the circulating pump set in action. A continuous circulation of the gas in the apparatus was kept up, as long as further diminution of pressure showed that absorption was still going on. When this ceased, cock *b* was closed, and by means of the Topler pump, the gas from the whole apparatus was pumped into the main gas-holder *y*, where it was shut off. More air was now admitted, and the whole process repeated, using (with *e* open and *f* closed) the auxiliary gas-holder *z* only. After absorption had ceased, the gas was pumped into the main holder, and so on till this was filled. When in this way the limit of capacity of the apparatus had been reached, the gas was circulated again for several hours; then the carbide was changed, the vessel exhausted and reconnected, and the circulation kept up for two days, though no further absorption occurred. The purity of the gas obtained was ascertained by determining its density, which was found to be 19·94, by sparking with oxygen, and by the spectroscope.

An improved method of this kind has recently been introduced[1] in which a continuous reaction takes place, the argon being driven off into a gas-holder quite automatically and in any degree of purity.

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[1] Percival, B. P. 903/1919.

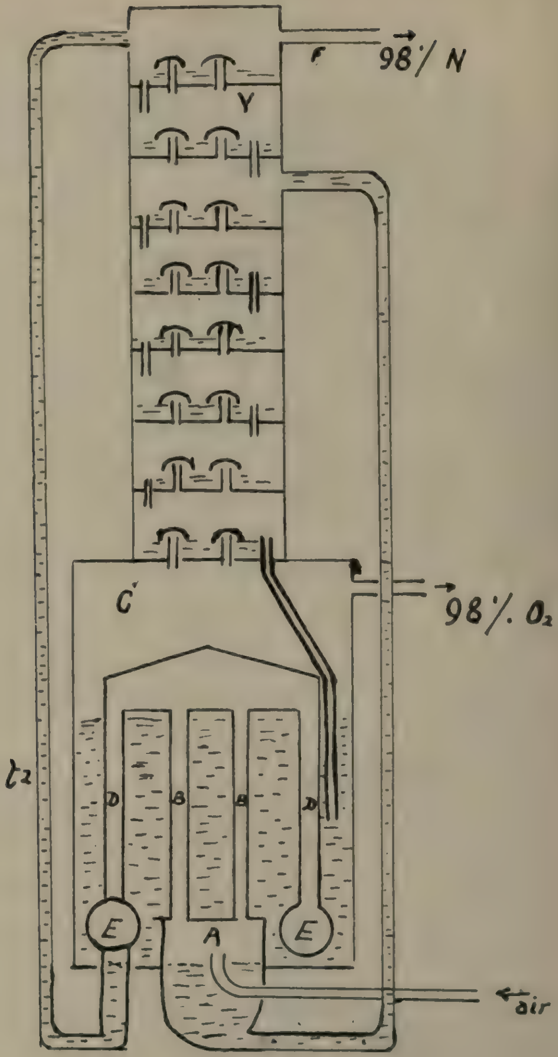


FIG. 14

SECTION OF CLAUDE FRACTIONATING COLUMN

It is a peculiar fact that in liquid air the percentage of argon is considerably higher than in the atmosphere, a condition which is produced by the evaporation of

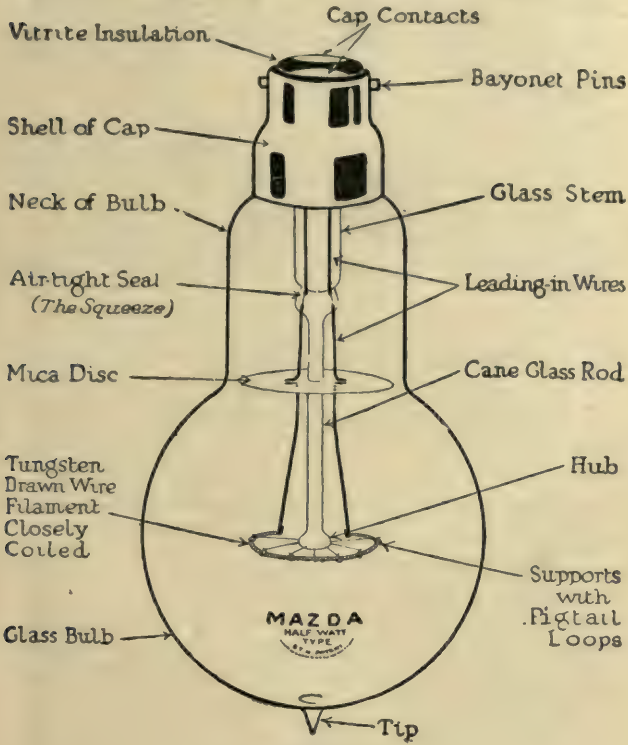


FIG. 15
HALF WATT LAMP

some of the nitrogen which boils at 195·7° C., while argon and oxygen boil at 186·1° C. and 181·5° C.

By allowing a vessel of liquid air to evaporate, the residue becomes richer and richer in argon, until most of the nitrogen has escaped. The very last drop will be practically pure oxygen.

Owing to physical laws which govern the evaporation, there is not a sharp end point, at atmospheric pressure, where the nitrogen ceases and the argon begins, but the composition varies as shown.

By increasing the pressure and causing the cold gases escaping to recondense to some extent, it is possible to remove the nitrogen in a nearly pure state, leaving the liquid argon and oxygen for further distillations.

The principle involved is described by Claude, from whose work on Liquid Air the illustration is taken. (Fig. 14.)

Cooled air under pressure is introduced into the vessel A and ascends the tubes BB′, which are cooled in a bath of liquid oxygen. Here the greater part of the oxygen and some nitrogen are condensed, and the liquid falls back into the reservoir A. The gas next passes down other tubes DD′, which are also surrounded by the liquid oxygen, and here the nitrogen is condensed almost completely, and collects in the reservoir E.

The upper part of the apparatus consists of a rectifying column, similar in construction to that of Coffey's Still. By the pressure of gas in the tubes the liquid in the reservoir A is forced up the tube t_1 and delivered into the column at a point a little below the top, while the liquid in E is similarly forced to the top of the column through the tube t_2.

The oxygen in C is at its boiling point under atmospheric pressure, and the highest temperature is found in this liquid and at the bottom of the rectifying column. On the other hand, the liquid in E, when suddenly placed under atmospheric pressure at the top of the column, boils rapidly, losing the greater part of its nitrogen and producing the lowest temperature found in any part of the apparatus. As the liquid passes down the column it becomes steadily warmer, and meets a current of gas which becomes steadily cooler as it ascends. The net result of these heat interchanges is that practically all the oxygen in the ascending gas is liquefied and drops back into C, while all the nitrogen in the descending liquid is distilled off and passes out into the atmosphere at F.

Now most of the argon is contained in the liquid oxygen, so that by a repetition of the process already described it is possible to again separate the two liquefied gases, yielding nearly pure argon, *i.e.*, argon free from nitrogen.

CHAPTER V

LAMP MACHINERY

Lamp machinery is now a specialized branch of engineering in consequence of the rapid development of the industry, and automatic equipment has now replaced, to a very great extent, systems of hand working which depended so much upon individual skill and care. Some of the minor operations are so simple that hand-work is cheaper, but in cases such as welding the leading-in wires together and for making the seals, also in the later stages of exhausting, mechanical methods are more reliable.

Filament is cleaned by running it through an atmosphere of hydrogen in a small closed box. Contact is made with the wire by two mercury cups, one at either end of the box, the filament being heated to a dull red by passing current through. The diameter of the wire is measured and the current controlled by an ammeter in circuit, each size of wire having a corresponding amperage to be run at, so ensuring an even heating effect throughout the entire spool of wire. When the spool is complete the machine automatically stops. One girl can look after several such machines and accomplish more work of greater regularity than by hand.

Very often, to reduce operations, the wire after cleaning is taken direct on to the forming machine, where the necessary zig-zag set is put into the wire to ease the work of mounting on the stem.

Funnelling machines are designed to turn out many thousands of sections an hour. Pieces of glass tube, cut to the required length, are inserted in cups fixed on a vertical wheel. As they pass upward and away from the girl feeding the machine, the ends are warmed, and then strongly heated in a blow-pipe, also at the same time a water-cooled arm comes round to work the soft glass into shape. The movement is so timed that each piece of glass is in the flame the same time, calculated at the minimum for flanging, and after moving out of the flame comes in a direct blast of air to produce a rapid settling. The chucks in which the glass tubes are placed rotate at a slow speed, governed by the rate at which the main wheel is moving. For an operator feeding quickly the machine moves more rapidly round, increasing the blast of the blow-pipe to speed up the melting of the glass. After flanging and setting, the parts move through a chamber, in which the temperature is gradually reduced, annealing the sections before being ejected into trays underneath.

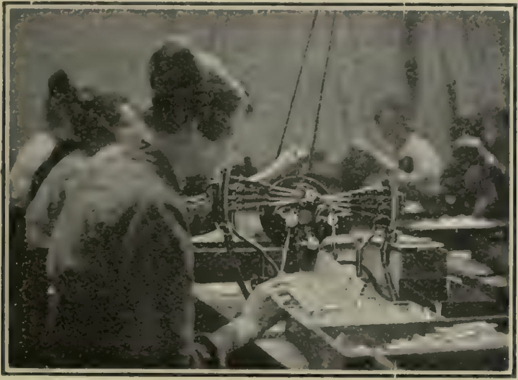


FIG. 16
FUNNEL MAKING

A machine for fixing the stem in the funnel is another example of very high engineering skill, in designing a labour-saving device, several types of which are now to be purchased chiefly from America and Germany, the basic principle being very much the same.

In most of the machines the movement of a circular table is utilized, so that feeding and removing may be done by the same person seated comfortably in front. This method is adopted in the stem-making machine, where the funnel is held in a vertical position between light spring clips, the leading-in wires and cane glass stem being similarly held. The sections in position move away toward the left, becoming heated at the point where the seal is to be made, and when sufficiently

FIG. 17

STEM MAKING MACHINES AT OSRAM LAMP FACTORY hot, mechanical jaws are brought together as the flame is removed, imbedding the wires and forming a perfectly homogeneous weld between the cane and funnel.

The Kremenezky and similar machines, are used for inserting the support wires into the buttons on the glass stem. The wires are drawn off reels, arranged radially according to the number of wires to be inserted, and are advanced toward the bead, which is softened in a blow-pipe flame. Immediately before the wires are inserted the flame is reduced, so that the wires do not become oxidized. As the glass cools and holds the wire, the length is cut off, the slides move away, and bring the wires forward as another stem is brought into position. Machines of this nature are highly complicated in design, so that it is only possible to give the very barest outline of the working, but by reference to B.P. 19,838/13 very minute mechanical details will be found.

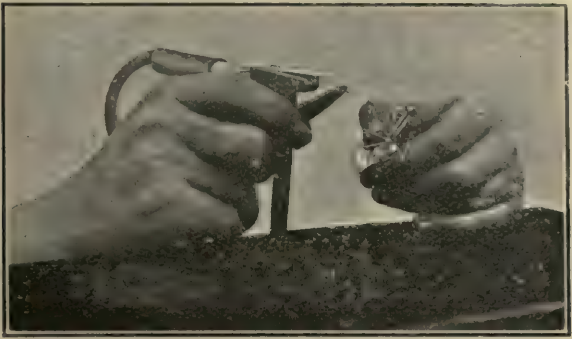
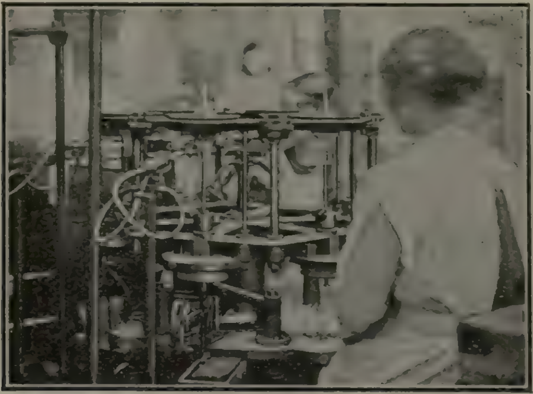


FIG. 18

INSERTING SUPPORT WIRES

It is now very uncommon to find the sealing-in operation of ordinary standard type lamps done by hand, as speed, finish and general efficiency are items of very considerable importance at a stage when much toward the completion of the lamp has been accomplished. The illustration Fig. 19 shows reasonably well the general idea involved in manipulating the two parts of the lamp preparatory to exhausting. The holder grips the two parts firmly in position, which, while rotating, are heated by Bornkessel burners at the point where the parts are to join. There are usually a series of holders so that the operation can be done gradually but continuously. As one lamp is being removed the parts for another are inserted; in a second arm a preliminary heating is taking place; on the third arm the sealing is done, while on the fourth arm the sealed-in lamp is cooled and afterward removed by hand and placed in a suitable annealing pot to prevent cracking.



Edison-Swan, Ltd.

FIG. 19
SEALING MACHINE

Reference has been made to the use of platinum substitutes in the manufacture of the stem, and while the new cheaper alloy wires may be carried right through from the cap of the lamp to the support wires, it is just as customary to use copper wire, joined to nickel by means of a short length of alloy for sealing into the glass. It is obvious that such an operation must be done very rapidly and accurately to avoid high cost on a small operation. Although girls in the factory attain an extraordinary speed, welding the sections by bringing the ends together in a needle blow-pipe, an expert worker only produces 400 to 500 per hour, while a machine, such as is illustrated, will turn out 2,500 pieces in the same time at less cost. The wires are fed from spools and welded electrically in an atmosphere of hydrogen and nitrogen, being cut off as the section is completed. One girl can look after several such machines where necessary.

Where spiral filaments are required, as in the case of motor and gas-filled lamps, the filament is fed from reels on to an iron wire, stretched very tightly between clamps, or in cases for continual working, between spools to maintain a continuous supply of mandril wire. The mandril rotates at a very high speed, the pitch of the turns being controlled by a very carefully cut gear. The mandril and filament cut to length are then separated, either chemically or mechanically, after which the flexible spiral is ready for mounting in the stems.

Automatic exhausting machines are used in America for the manufacture of low voltage lamps, and are designed to pump, seal off and remove 1,000 lamps a day with one girl inserting.

The tube on the lamp for exhausting is fixed to the pump by means of a short rubber connection just "wetted" with oil. The operator has nothing to do except watch for leaks.

Capping is invariably done on a rotating table, the bulb and cap (which is filled with cement) being held together by light springs. As the lamps so arranged pass round, the cap portion is heated gently and then carefully cooled to avoid cracking. The cement is by this means set and the complete lamp removed and placed in a tray at the side, being periodically taken away to the test-room as the trays are filled up.

CHAPTER VI

THE ARC LAMP

THE arc lamp, as developed mechanically, hardly comes within the scope of this small work, but any account of the electric lamp industry in general would be incomplete without reference to the production and development of the electric arc as a means of illumination.

During the Great War the value of the arc light was particularly realized, the enormous demands made upon the forces only being possible by the use of this system in searchlights, giving thousands of candle power, without which air raids might have held more terrors and been more difficult to combat.

The system is essentially one for circumstances necessitating considerable illuminating power, and, while useful and economical under certain conditions, the difficulty of using small units, with the trouble of renewals and adjustment, has so far not been sufficiently simplified to allow competition with the filament lamp for domestic purposes, but for searchlights, goods yards, factories, and shops of large area, the arc lamp is still particularly useful and efficient, though in many cases it is being replaced by high candle-power half-watt lamps.

As the filament is the vital essential of the incandescent lamp, so the carbons in the arc lamp are the first factor of importance. The utmost care is necessary in manufacturing carbons of the right quality—density, composition, electrical resistance, all having effects on the burning of the lamp, making or marring the efficiency.

Lamp carbons are usually made from a mixture of ground glass, coke and lampblack, worked into a stiff paste with tar, the plastic material thus produced being squirted through steel dies by means of hydraulic presses. Unless exact conditions, such as viscosity, temperature and pressure are maintained, the paste cracks or flattens out before it can be further treated. If sufficiently uniform and solid, the soft rods are packed into small boats and baked in a specially designed furnace, in which the volatile matter in the mixture is driven off, leaving as residue carbon as a dense uniformly straight rod. Uneven or too rapid furnacing causes bent and cracked rods, one of the chief causes of loss in manufacture.

On bringing two carbon rods together across which a suitable voltage is applied, and again moving apart, a vapour stream of carbon-vapour will be formed in consequence of the contact points becoming highly incandescent and so evaporating a portion of the carbon. This gap of gas continues to conduct the current from one electrode to another, by which action the light from the hot carbons is maintained as long as they are kept relatively close together, so that the resistance of the gap is not increased beyond the critical limit.

On examination of the carbons while running on direct current, a variety of conditions are observed, which collectively produce the intense light associated with the arc.

The stream or flame of carbon-vapour between the two poles really consists of an inner and outer core, the former violet in colour, the latter more greenish, but very little light is emitted from this source. One carbon burns, forming a hollow or crater, the other tends to build up to a peak, and it is from the crater or positive (written +) that about 85 per cent. of the light is given, but since it burns away more rapidly than the negative, the size has to be double to allow for the additional loss. With alternating current both carbons are of the same size, light being given equally by each carbon.

The carbons are usually arranged vertically, the top one being fed mechanically, while the lower one is fixed, but loss of light due to the interference of the negative carbon often requires rearrangement in cases where a point of light is necessary, such as for searchlights, the crater being focussed on to a parabolic mirror, and the peak only of the negative being visible, as a result of running the lamp with electrodes at right angles. For general illuminating purposes this is not permissible, as equal distribution of light is necessary.

The enclosed arc is a more economical type of lamp in which the carbons burn in a glass chamber, closed in except at the top, which is open to allow fumes to escape. The rate of combustion due to exclusion of air is reduced so considerably that carbons will last six or seven times as long, which for many purposes is a particular advantage, such as in street lighting, where ordinary carbons have to be replaced daily. But, owing to the loss of light, due to absorption of the enclosing globe, the efficiency is somewhat reduced. Neither is the lamp suitable for interior use owing to the objectionable gases generated.

The trouble of the shadow and unpleasant cold blue colour of the light with ordinary carbons has been overcome to some extent.

It is fairly well known that chemicals of various kinds impart different colours to flames as exampled in pyrotechnics. By adding such chemicals as sodium and calcium fluoride to the carbons during manufacture, it is possible to impart to the flame between the poles of the arc very considerably luminosity. The flame of the ordinary carbon gives only about 5 per cent. of the total light, but with impregnated carbons 65 per cent. of the light comes from the flame itself. Flame carbons, unfortunately, burn away very rapidly, so that extra long lengths have to be used to balance the consumption, and to increase the mechanical strength and conductivity a core of metal is usually placed in the carbons, which also has the additional advantage of steadying the flame. Instead of having the electrodes vertical it is possible with the flame arc to arrange them at an acute angle, which gives light free from the shadows with the ordinary type of lamp.

It has already been pointed out in the chapter on carbon filament lamps, that carbon has the disadvantage, for lamps at any rate, of boiling below its melting point, a characteristic of very few substances of a refractory nature. Now it is a peculiar physical phenomenon with most substances that electrical conductivity increases with temperature, as in the case of the Nernst filament, which, after heating by means of an auxiliary filament, becomes a sufficiently good conductor to allow the current to pass. At the temperature of the carbon arc all substances are vaporized, and in a gaseous state enter the arc stream, conducting current and entering into the spectrum of the flame, as in the case of the flame arc just referred to. With pure carbon electrodes an exceptional arc is produced as distinct from a typical arc, as exampled in the magnetic arc invented by Steinmetz, which depends for its efficiency on the light emitted from the gaseous spectrum of the materials used, as distinct from the luminous effect of an incandescent in the carbon arc.

In the Steinmetz lamp the negative electrode is composed of the mineral "magnetite," an oxide of iron pressed into an iron case; the positive is a solid copper rod which is so calculated that while remaining sufficiently hot to prevent any deposit forming on the surface, the temperature is not sufficiently high to melt or oxidize it. The negative, which does not burn away, is arranged permanently fixed over the magnetite cartridge, so that a molten pool is formed in the centre. If iron oxide only was used, the arc would wander and splutter in consequence of the boiling of the liquid, for which reason chromium or titanium oxide is added, which, being more refractory, holds the iron in a more plastic condition, and overcomes what would otherwise be a serious defect.

In addition to the colour of the light, the great advantage of the magnetic arc is its economy of life. Only one electrode has to be replaced, and this only once every 150 hours. The ordinary carbon burns away fifty times more rapidly, so that for outdoor lighting the high efficiency of both light and life, this type of arc lamp has become very popular, particularly in America, where it is used extensively for street lighting.

In striking an arc, mechanism has to be arranged by which the two poles are first made to touch. The action would be a dead short circuit of the current if a balance, in the form of a resistance, was not introduced to take up the sudden rush of energy. The solenoid is made to perform the double function of striking and feeding the carbons, the necessity of which makes the size of the lamp rather cumbersome in appearance.

The general principle is illustrated in the diagram where the bottom carbon (A) is fixed, and the top carbon, moving vertically in a holder, drops down into contact with the bottom carbon when current is not passing. When the current is switched on the circuit is completed through the electro-magnet S, holder C, top carbon B, bottom carbon A. The magnet gives a fairly long stroke, so that the carbon is lifted up considerably by the pivoted movement of the arm acting automatically.

When this magnet S comes into operation and lifts

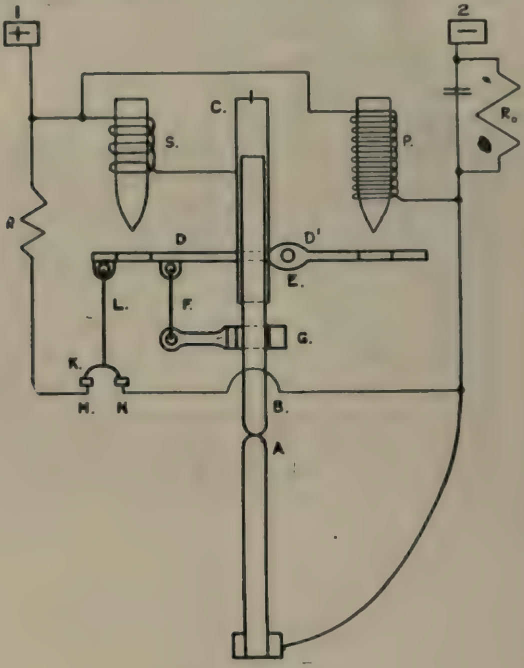
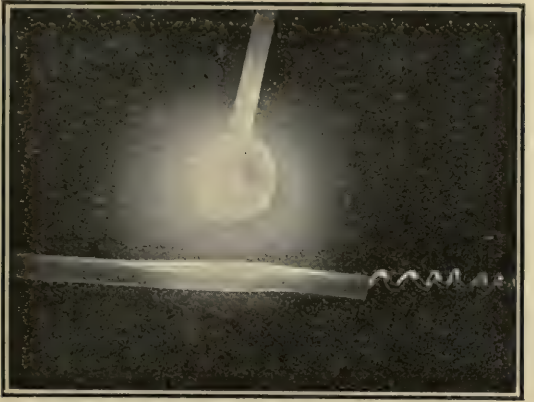


FIG. 20

METHOD OF STRIKING ARC

the electrode, the arc formed lengthens, and a circuit is formed through the solenoid resistance P, which effect finally balances the circuit through S, which brings the movement of the lever, and, therefore, the carbon, to rest. As the combustion of the carbons takes place, the voltage through P increases in consequence of the lengthening of the arc, and therefore exerts an extra pull on the lever, which allows the carbon to gradually fall, maintaining a regular length of arc. Finally, a point is arrived at where the clutch G becomes horizontal, allowing the carbon to fall through the vertical sleeve, and so in contact with A producing a repetition of the movement described.



Edison-Swan, Ltd.

FIG. 21

CLOSE VIEW OF "POINTOLITE" ARC LAMP

At the extreme end of the lever is a rod in connection with a contact maker. If the carbon breaks away the magnet P continues to draw the lever up as the voltage increases, until such a time that contact is made at M, thus closing the original circuit as the current passes from 1 to 2 through the resistance R.

It will be seen from the foregoing remarks that in consequence of the very variable design it is not possible to give definite details of manufacture as in the case of the filament lamps, but of recent years an arc lamp, similar in design to the vacuum lamp, has been placed on the market by the Edison-Swan Electric Co., Ltd., of England, which, while giving a point source of light, possesses the additional advantage of being highly efficient in small units.

As described by S. R. Mullard[1] the lamp consists of a spherical glass bulb, containing a tungsten globule and a rare earth ionizer. A pressure of a few inches of nitrogen is introduced into the bulb after evacuation. The cap of the lamp contains three pin contacts, by which the current may be made to flow through the ionizer or between the ionizer and the tungsten electrode.

The lamp is used in connection with a series resistance to take up the first rush of current, when the ionizer is made incandescent.

Normally no current will pass from the ionizer to the tungsten ball, but by heating the gap sufficient conductivity of the gas is obtained to produce an arc, the globule becoming white hot and emitting a brilliant white light.

The arc is made by forcing a spring switch down, making circuit through the resistance and ionizer, or filament. After a second or two, during which period the ionizer begins to glow like a Hernst lamp, the switch is released, and in moving back breaks the ionizer circuit, allowing the current to flow between the globule and the rare earth filament, producing an arc effect as described.

A great advantage of the lamp is its compactness for purposes where a point source of light is required, with the advantage of the arc efficiency without its defects, and the simplicity of the filament lamp with the advantages of a concentrated source of light.

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[1] Illuminating Engineering Society, 1915

CHAPTER VII

VAPOUR LAMPS

WITH vapour lamps illumination is due to an arc or a glow discharge, through a gaseous conductor.

The development of these lamps has passed through two distinct phases, that of Way's discovery of the luminosity of an arc formed by breaking in air a current carrying mercury jet, and the second phase which developed the gaseous discharge into a practical source of light. This was the result of objections by illuminating engineers to high temperature, high intrinsic brilliancy illumination, and an attempt to approach a cold source of light produced two successful types of the lamp, the Moore tube and the Neon tube.

The names most prominently associated with the development of the vapour lamps of the first type are those of Cooper-Hewitt and Kuch ; those most prominently associated with the development of the second type of this lamp, Moore and Claude. These two types of vapour lamps differ vastly in theory, in construction, in mode of operation, in physical characteristics, in defects and advantages, and future possibilities.

Owing to the novelty of the vapour lamps, and to a certain complexity of behaviour as compared with more simple illuminants, satisfactory theories of their behaviour have been developed only recently and even now are incomplete.

It would be, therefore, advisable to consider the theory of the physical phenomena of the vapour arc and the glow discharge, before proceeding with the study of the lamps themselves.

The following briefly is the interpretation of the phenomena of the glow and arc discharges given by Sir J. J. Thomson.

(1) **The Glow Discharge.** In order that the discharge might take place, the ionization of the gas must be produced by the electric field close to the cathode. It may be supposed that the ionization is due to the + ions, which under the influence of an intense electric field near the cathode acquire sufficient energy to act as ionizers. The + ions in their journey towards the cathode collide with and ionize the molecules of the gas around the cathode, this producing — ions, and finally strike the cathode and communicate sufficient energy to the — ions in the surface layer of the metal to enable them to leave the cathode and pass into the gas near it.

The — ions, which are produced in these ways, are repelled by the electric field away from the cathode, and soon acquire sufficient energy to ionize the molecules of the gas by collision, thus enabling the discharge to take place, and also keeping up the necessary supply of — ions near the cathode necessary for the continuance of the phenomena.

The electric field must be very intense near the cathode, but in the rest of the tube it need only be sufficiently strong to enable the corpuscles to ionize the gas. The luminous stage of an atom is reached when the energy stored by it reaches a certain critical valve. The quantity of energy stored by the atom will depend upon the corpuscles striking it, which would depend upon E.M.F. used, and upon number of impacts, which would depend upon the current.

The appearance of luminosity is quite abrupt. E.M.F. required often greatly diminishes with increase of current, while increase of current often greatly increases luminosity.

The discharge is, in a sense, a cold source of light, since the collisions of corpuscles with atoms primarily increase the internal energy of the latter, while only indirectly and to a small extent increasing the temperature of the gas.

(2) **The Arc.** The arc is a type of a low voltage discharge. First, the cathode is raised to a temperature sufficiently high to enable it to emit – corpuscles, which, if the anode is cold, serve to carry the entire current.

Whether the heating of the cathode is due to the Joul effect resulting from a touching and separation of the electrodes, or whether the result is achieved by auxiliary pre-heating of the cathode does not matter.

So long as only – corpuscles carry the current, the electric force increases from cathode to anode, and increases rapidly with the current. Now suppose that the bombardment of – corpuscles heats the anode to an extent sufficient to enable it to emit + ions. These rapidly diffuse through the gas between the electrodes, making the electric field uniform except close to the electrodes. The + ions have a two-fold function. They help to carry the current, and bombard the cathode, keeping it hot, and thus maintaining the supply of – ions. Besides the ionizing phenomena described above, there is the additional ionization of the gas by collision, though, owing to low voltages used, this effect is much smaller than in a glow discharge.

If cathode, and especially both cathode and anode, are preheated, a very small potential will suffice for a passage of current. The essential feature of the discharge is a hot cathode. The anode must generally be hot, too, to provide + ions for bombarding the cathode and keeping up the latter's temperature, but an arc between a hot cathode and a cold anode can be easily formed.

This explains why, until a few years ago, experimenters failed to produce an A.C. low voltage arc between metallic electrodes and maintain the arc; the rapid cooling of the constantly changing cathode due to good conductance of the metal, caused the arc to go out at reversal. Similarly, this explains the action of the mercury rectifier.

The mercury arc was first used as an illuminant by Way in 1860, but the first mercury arc lamp—the earliest of vapour lamps—did not appear until 1892, when Arons produced a successful laboratory type. The lamp is shown in Fig 22. It is started by tilting, so that a drop of mercury flows from one limb into the other. An arc is formed between H and H, and fills the whole U-shaped tube. Unless current in the lamp is weak, the lamp overheats badly, and in laboratory use water-cooling has often been resorted to. According to Geer, the lamp has given between 41 per cent. and 48 per cent. radiant efficiency at an arc voltage of 14 volts and currents from 5 to 9 amps. The Aron's lamp was, however, only a laboratory article, and it was left to Cooper-Hewitt to produce, in 1900–1901, the first commercial mercury arc. Since that date, Cooper-Hewitt and others have produced a number of modified and improved types of lamp. The Cooper-Hewitt mercury arc lamp consists of an evacuated glass vessel, in the form of a long tube with extensions at the ends containing the electrodes, the cathode being a

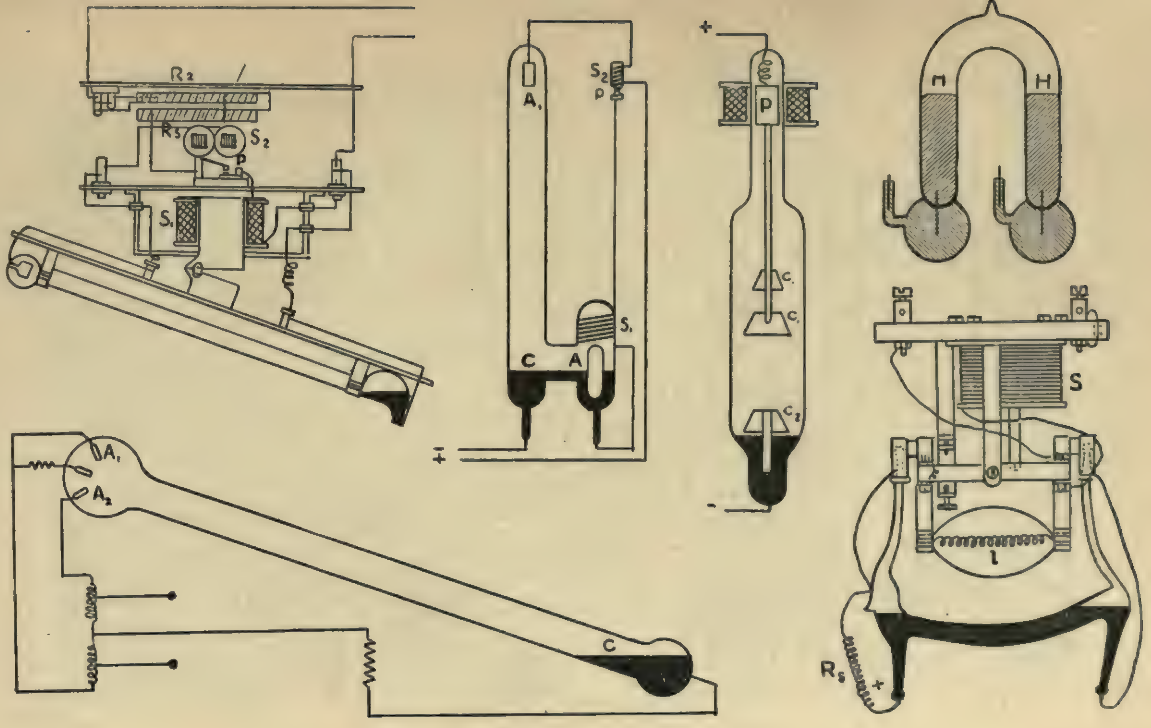


FIG. 22.—TYPES OF VAPOUR LAMPS

pool of mercury, and the anode a graphite cylinder or an iron cup. A platinum seal is used. The problem of starting has been tackled in various ways, and there are several methods used in practice with more or less success. The lamps can be divided into two classes—those that are started by hand-tilting, and those that start automatically. The second class includes lamps started by magnetic tilting, by an initial high tension discharge, or by an auxiliary arc.

When the lamp is alight the mercury column completely fills the tube, emitting a greenish blue light of an intrinsic brilliancy of about 12 c.p. to the sq. in. A closer study of the various types of the Cooper-Hewitt mercury arc is fully warranted by the importance of the lamp.

The lamp, in the form of an exhausted long straight glass tube, is usually about fifty inches long and one inch in diameter, with an extension at one end containing the carbon or iron anode. The end of the tube containing the anode is generally of a larger diameter to enable the mercury vapour to recondense there and flow back to the cathode. The mercury vapour is mainly due to distillation of mercury from the heated cathode region towards the cooling chamber at the anode, and partly to projection of mercury particles from the cathode towards the anode by the electric field.

The temperature of the lamp is low, and the phenomena of light is a phenomena of mercury luminescence and not of temperature radiation. The resistance ampere and volt ampere characteristics of the arc are peculiar. Up to a point they resemble the usual — arc characteristics, and then the resemblance ceases. As the mercury arc is started and mercury vapour fills the tube, the voltage drops at first rapidly, and then more slowly with increase of current becomes stationary and then begins to rise, first slowly, then more rapidly, and the resistance of the column of mercury similarly first shows a – coefficient with increase of current, and then with a further increase of current a + coefficient.

This is due to the fact that the mercury arc, unlike a simple open-air carbon or metal arc, alters in temperature and vapour density owing to its dimensions being kept constant by the enclosing vessel.

At first, the typical — characteristic of the arc is observed, but as current is increased further, temperature rises so that the cooling chamber of the lamp can no longer condense with sufficient rapidity, the pressure of the mercury vapour increasing greatly and resistance of the column increasing in consequence.

The influence of external cooling on the characteristic of the mercury arc is very marked, which has been shown by Dr. Rechlinghousen, and explains why mercury lamps, where cooling accommodations are insufficient, sometimes go out and after a while start up again. The lamp gets over-heated, the resistance of the vapour column and the voltage necessary for the given current greatly increase, and we get an effect analagous to that which is observed in a carbon arc which has become too long; the voltage is insufficient to maintain the arc, and the lamp goes out. It restarts again when it has cooled sufficiently. Of the volts absorbed by the arc, about eight volts are dropped at the anode and about five volts at the cathode, this drop being approximately constant. The rest of the voltage is absorbed by the column of mercury vapour. The drop in the column is proportional to its length and inversely proportional to its diameter. The maximum efficiency of the mercury arc is obtained by operating it near the critical point of the voltage ampere curve, and therefore a ballast resistance and an inductance arc used in series with the arc to balance voltage fluctuations.

The important problem of starting the arc has been solved in a number of ways.

The Cooper-Hewitt lamp is normally in an inclined position. To start the arc, the switch is closed and the chain attached to the lamp-frame is pulled, tilting the lamp so that the mercury flows in a thin thread from the cathode to the anode. Contact is thus established, and when the chain is released and the tube returns to the normal position, the mercury thread is broken and an arc is formed, soon filling the whole tube. The disadvantage of this type is that a double operation is necessary for starting.

With the auxiliary arc method (see illustration), on switching on, current flows from + terminal through the contact P, through the solenoids S, through mercury anode A_2, cathode C, and out at −. The iron float is lifted by the action of S, the level of mercury in C and A_2 falls, breaking the thread connecting them and forming a small arc. The arc soon renders the whole of the space in the lamp conductive, so that an arc is formed between the main anode A, and the cathode C, and the solenoid S_2 breaks the circuit of the auxiliary arc, interrupting it at P. Should the cut-out S_2 not operate and the auxiliary arc persist, no harm would be done; in fact, the action of the main arc would be steadied. This method has the advantage of enabling the tube A. c. to be in an inclined or vertical position as required.

Magnetic Tilt Type of Cooper-Hewitt Lamp. With a magnetic tilting device, current flows through the tilting solenoid S, cut-out P, substitute resistance R_s and through series resistance R_z back to the line.

The solenoid S tilts the tube and the mercury thread from the cathode joins it to the anode.

Now a parallel path is provided for the current through the mercury, induction resistance S_2, R_2, and back to the main. S_2 operates cut-out P, the tube returns to the normal position, the arc is formed, and the current takes the path through the mercury arc, S_2, R_2 and back to the main.

With the High Tension Method of Starting. When the switch is closed a current flows through an induction coil, the circuit being immediately afterwards broken by means of a "shifter." The induction coil discharges through the mercury arc tube, breaking down its resistance, and the arc current follows through the now ionized space. A metal band is placed round the lamp near the – v end, and connected to the – main to produce condenser action.

So far, all types described are for use with direct current, for the arc could only pass if the mercury were a cathode, and would immediately go out when the current passed through a zero value.

A modified Cooper-Hewitt lamp is designed to operate on a single phase supply. Two primary and one starting anodes are used, A1 being used for one-half wave of current and A2 for the other. The anodes A1 A2 are connected to the ends of a secondary of a transformer, and C to the neutral point, and reactances in the circuit are so designed that the two half-waves overlap, and the current to C is never zero. A.C. lamps have also been used successfully on polyphase currents.

From point of view of life and efficiency the Cooper-Hewitt lamps are very satisfactory. Their efficiency is of the order of 0·5 watts per candle, and their life, which is only limited by deterioration of vacuum, has been found by Croft to be on the average about 8,000 hours.

The following are some of the records of typical Cooper-Hewitt lamps given by Croft—

Type.	Length.	Average M.H.S.C.P.	Average Watts.	Watts. M.H.S.CP.
D.C.	21″	300	102	0·64
D.C.	45″	700	385	0·55
D.C.	50″	800	385	0·48
A.C.	50″	800	400	0·50

These results are very creditable. Further, lamps can be designed for all sorts of voltages, typical ones being 100–124 volts D.C., and 100, 110, 120, 200, 220, 240 volts A.C. Yet, though possessing a number of great advantages, the lamp has failed to make headway, chiefly owing to its unpleasant greenish-blue colour. Its light is peculiarly selective as seen from the graph illustrating the range, most of the mercury arc radiation being in the ultra-violet, and the visible portion almost exclusively confined to the green-blue end of the spectrum. Hence the lamp could only give satisfaction for such purposes as photography, newspaper printing, drawing office and the store houses where the colour of the light is of small importance.

Recognizing the drawback of an unpleasant colour to an otherwise efficient source of light, a number of experimenters have attempted to improve the colour of the mercury arc by various more or less ingenious means. The problem was to introduce red rays into the spectrum of the lamp, red rays being practically absent from the mercury spectrum.

Cooper-Hewitt tried to achieve the result by use of fluorescence. He tried the effect of wrapping the lamp in a piece of silk impregnated with fluorescent substances, but found that though he improved the colour of the light he lost 25 per cent. of the efficiency. Then he experimented with fluorescent reflectors, and finally produced a rhodamine coated reflector which adds a certain amount of red rays to the light of the lamp, but which has not proved very successful.

A number of experiments were tried, notably by Leblanc and Heraeus to improve the colour of the light by adding other substances, such as zinc, to mercury. These attempts were a complete failure. Leblanc found that the arc passed one or the other of the substances used, but never in a mixture of both. Heraeus found that an added metal tended to gradually separate out at one of the poles.

The first successful attempt at improving the colour of the mercury lamp was to underrun a carbon filament lamp in conjunction with the mercury arc, both being enclosed in a diffusing globe; which later was very successfully developed by Kuch, who produced the very efficient quartz mercury arc which combines improved colour with high efficiency.

The lamp itself is shorter and of larger diameter than the Cooper-Hewitt type. Both electrodes are of mercury. The lamp is started by magnetic tilt. When the lamp is switched on, current passes through the tilting solenoid S, underrun carbon lamp C, through starting resistance R_s, through the mercury column in the tube and out at the −. The solenoid S tilts the tube so that the mercury column in the lamp is broken close to the − pool, an arc is formed, and the pressure of vapour immediately drives the liquid mercury in the tube into the anode chamber, short circuiting the starting resistance R_s. The arc now fills the entire tube, burning between two mercury electrodes.

The voltage of this lamp is between forty and sixty volts, current about 0·65 amps., C.P. about 80, efficiency about 0·4 watts per c.p., and life about 3,000 hours or more.

The quartz mercury arc lamp was originally invented by Kuch and largely developed by Westinghouse. The essential feature of this lamp is substitution of a transparent quartz envelope for the glass tube, previously used in the mercury arc. The use of a quartz tube permits the use of much higher temperatures and pressures within the lamp. By use of a very high temperature, and pressure in the neighbourhood of an atmosphere, the inventor has achieved a number of very important results. Resistance of tube has been greatly increased, and its dimensions correspondingly decrease, thus instead of a tube 100 cm. long, 3·4 cm. diameter for 110 volts, Kuch used tubes only 8 cm. long, 1·0 to 1·8 cm. diameter for the same voltage. The efficiency of the lamp has been greatly increased, modern types having an efficiency of about 0·22 watts per c.p. Finally, the narrow spectrum lines of mercury have been broadened and the light made more like white light by super-imposition of temperature radiation on the luminescent effect of mercury. The use of tantalum or platinum stud for the anode has also been successfully tried for an additional production of red rays.

This lamp, when used for ordinary illumination, must be enclosed in a glass globe to protect the users from the ultra-violet radiation. The strong ultra-violet light, produced by the lamp, has been used with very satisfactory results for chemical purposes, sterilization of water, etc.

The life of the lamp is some 3,000 to 4,000 hours.

The Cadmium and Thalium Arcs have been invented only recently, and their claims have not yet been definitely proved by commercial usage. They are, each in its way, the development of the quartz mercury arc. The cadium lamp, which was produced in 1912 by Wolfke, uses a mercury cadmium amalgam instead of pure mercury as a source of luminous vapour. An amalgam consisting of specially purified cadmium and 3 per cent. to 10 per cent. mercury forms the cathode, and a graphite cylinder the anode. The envelope of the lamp is made of quartz. The amalgam is solid at normal temperatures, and hence when the lamp is extinguished a thin metallic deposit is formed on the walls of the tube, but this deposit vanishes when the lamp is in operation, and is, therefore, not detrimental to the light of the lamp.

Starting can be achieved either by utilizing the conducting metallic deposit on the walls of the tube for the initial conducting path, or by having the graphite electrode joined to the anode seal by an iron chain and starting the lamp by direct electrode contact by means of tilting. A consumption of only 0·2 watts to the Hefner candle is claimed for the lamp. The colour of the light is white.

The Thalium Arc, as produced by Cooper-Hewitt in 1916, is specially designed for production of ultra-violet light and is intended to be used for chemical and medical work, and not for ordinary illumination.

A quartz tube is used, and the anode and cathode are of mercury and thalium respectively. A calcium cathode may be used instead of the thalium one. As both calcium and thalium are solid at normal temperatures, a starting band is used to vaporize some of the cathode material, thus enabling the arc to form. A large proportion of rays have a wave length of 2,000 to 400 microns.

The Nernst lamp, introduced in 1917, represents one of the very latest developments of vapour arc lamps.

Two distinct types have been patented. In the first type, an arc passes between two carbon electrodes in an enclosed glass bulb, an atmosphere of zinc chloride or zinc bromide being present. The vapour pressure is in the neighbourhood of one atmosphere. Aluminium or titanium may be substituted for zinc. The carbons should glow slightly, and the arc should not be less than 3 cms. The efficiency of this type is comparable to that of a quartz mercury arc. The salts are volatilized by external heater, which also acts as a series ballast resistance. The second type is more interesting than the first one, both theoretically and practically. In this lamp the anode is a long carbon rod attached to an iron plunger, which is electrically connected to the −v terminal of the lamp. The cathode is a pool of mercury to which a mixture of suitable salts has been added. The anode and cathode are in contact when the lamp is not working, and on switching on are separated by the action of the small solenoid which operates the iron plunger P. The salts are evaporated in the arc stream, and emit a very efficient white light.

The problem which Nernst had to face and overcome was the tendency, previously found by other experimenters, of the salts to separate out of mercury, leaving a mercury arc pure and simple. The problem has been very ingeniously solved by employment of glass cones by means of which salt vapours are continually injected into the arc stream. The action proceeds in the following manner. The lamp is sufficiently hot during running to keep the condensed salt vapours in liquid form, so that salt vapour leaving the mercury arc and separating out near the anode is condensed in the upper part of the bulb and trickles down, being guided by cones C, C1, upon the mercury pool beneath, where it is sucked in under the cone C2, re-vaporizes and passes back into the arc stream. The action is continuous. A particularly suitable salt mixture is 70 per cent. zinc chloride, 15 per cent. calcium chloride, and 5 per cent. thalium chloride. This lamp is designed for 120 volts, 4 amps., and the inventor claims for it a c.p. of 3,000 Hefner candles and a consumption of only 0·16 watts to the Hefner candle.

With this description of the Nernst lamp, the group of vapour arc lamp may be considered, for the present purposes, to be completed

Starting with a pyrotechnic display at the Isle of Wight some sixty years ago, the vapour arc lamp has developed into a practical source of light which, for combined long life and high efficiency, compares very favourably with the best known electric illuminants. There is no doubt that, since the light of this type of lamp is mainly due to luminescence of the vapour employed and not to temperature radiation, it is theoretically a more promising field for the engineers in search of a perfect light source.

In view of this, Kuch's quartz lamp and Wolfke's cadmium arc are in a sense a step backward, since in these lamps increased temperature radiation is responsible for increase of efficiency. However, vapour arc lamps, employing the vapour of a liquid or a solid for a luminous source, can never become "cold" sources of light, since heat will always be essential for production of the vapour.

Realizing this, and intent on the production of a cold source of light of low intrinsic brilliancy, a group of illuminating engineers turned their attention to glow discharges through permanent gases, and after much experimenting one of them, Moore, produced in 1916, the first successful commercial high tension glow discharge lamp. The Moore Tube and the more recent

Neon Tube invented by Claude, are at present the only types of the high tension glow discharge lamp on the market.

The Moore Lamp consists of a glass tube some 200 ft. long and 1¾-in. diameter, containing a suitable gas at a pressure of about 0·1 mm, of mercury and having sealed in its ends two cylindrical carbon electrodes eight inches long.

The two ends of this tube fit into a steel case containing a high tension transformer which operates the discharge.

Moore has experimented with a number of gases, and finally chosen two, nitrogen and carbon dioxide. Of these, the first emits a golden yellow light, and is more efficient than the second, but the second has the advantage of emitting a light that is probably the nearest approach to daylight obtained in artificial illumination.

For these reasons, the nitrogen Moore Tube is the one used for general illumination purposes, while for special purposes, when an approach to daylight is necessary, such as colour matching, the carbon dioxide Moore Tube is preferred.

The main problem of the Moore Tube is the rapid hardening of the vacuum, due to absorption of the gas by the walls of the tube. This difficulty has been overcome by means of a special feeding valve which supplies the necessary additional gas.

The valve tubing is vertically supported. Usually ⅞ in. diameter tubing is used, constricted at the bottom to ⅜-in.

A ¼-in. porous carbon plug is sealed into the ⅞-in. tubing, and is covered by about a thimbleful of mercury. The porosity of the plug, though sufficient to permit diffusion of a gas through it, is insufficient to permit the mercury to percolate through. A small glass tube, filled with iron wire and partly immersed in mercury, acts as the core of a small solenoid connected with the primary of the operating transformer.

By means of an adjusting screw at the top of the solenoid the degree of vacuum is kept normally at a lower value corresponding to point Y, avoiding the critical point when conductivity of the tube is maximum for corresponding degree of vacuum.

As tube hardens, current increases, the solenoid of the feeding valve operates, lifting the iron wire plunger, the level of the mercury in the valve falls, exposing the tip of the carbon plug, and gas diffuses through this plug into the discharge tube until the correct degree of vacuum is reached, when the valve automatically closes.

The degree of vacuum necessary is 0·1 mm. of mercury, and the valve regulates it to within 0·01 mm. of mercury. The slight oscillation in current, due to the alterations of vacuum, produces no appreciable variation in candle-power.

If the tube uses nitrogen, the gas feed is taken straight from the air, which on its way to the valve passes over phosphorus in an iron tube.

If the tube uses CO_2, a bottle containing a piece of marble and some hydrochloric acid automatically generates the gas when the valve is used.

Moore Tubes are built upon the customers' premises by sealing together 8 ft. 6 in. lengths of 1·75 in. tubing, $\frac{1}{16}$ in. thick, and exhausted on the spot, current being switched on shortly after pumping commences, the amount of light in the tube roughly indicating the degree of vacuum. A special gauge is used for an accurate pressure measurement. The most efficient length of the tube is about 200 ft., but shorter lengths are also constructed.

A special transformer must be used for production of the discharge.

40 - 70 ft. tube requires 1 2 k.W. transformer.
80–125 ft. ,, ,, 2·75 k.W. ,,
130–180 ft. ,, ,, 3·5 k.W. ,,
190–220 ft. ,, ,, 4·5 k.W. ,,

For purposes of a steady light a power factor of 65 per cent. had at first to be used, which necessitates the use of special shell type transformers, but later the tube was made to operate on a power factor as high as 84 per cent.

High frequencies are preferable for operation, but any frequency can be used, though at frequencies as low as 25 a flickering effect is observed unless polyphase currents are used. There is no change of efficiency with change of frequency. The Moore Tube has a consumption of 1·4 watts to the Hefner candle-power, a very low normal intrinsic brilliancy of 0·66 Hefner to the square inch, a very long life (10,000 hours have been given as an average), and has the special advantage of being reparable. Its external temperature is remarkably low—about 100° F.

The Neon Tube, invented by M. Claude of Paris, appeared some five years after the Moore Tube.

The invention was undoubtedly hastened by the fortunate circumstance that Claude was, at the time, dealing with very large quantities of liquid air, and had, in consequence, a large supply of rare gases at his disposal. Neon possesses remarkably low dielectric strength, and Claude found a voltage in the region of a 1,000 ample for operating his lamps.

A typical Neon Tube, used by Claude, is six metres long and 45 mm. diameter, using cylindrical copper electrodes, having a superficial area of 5 dcm.^{2} per ampere, and containing Neon at a pressure of about 2·9 mm. mercury. No feeding valve is used. The voltage across the luminous column is approximately inversely proportional to the tube diameter. A variation of pressure causes different effects for tubes of different diameter; thus an increase of the pressure 2·9 mm. usually employed raises P.D. in tubes of 67 mm. and 41 mm. diameter, and reduces it to those of 10·7 and 5·1 mm. diameter. Lighting intensity with a given current density is proportional to the diameter of the tube.

When considering the output of the luminous column, only very large and very small tubes are at a disadvantage. Quite satisfactory results can, however, be obtained with tubes of 4·5 mm. to 10 mm. diameter.

When lighting intensity furnished by a tube of a given length diminishes very nearly as its diameter, there is no loss of efficiency, a fact which enables a wide range of tube to be used.

A typical Neon Tube, six metres long and 45 mm. diameter, used 1,000 volts, 94 amps., has a consumption of about 0·8 watts/bougie, and a life of some 400 hours. The colour of light is red.

Lately, efficiencies as high as 0·5 watts/bougie have been claimed for the lamp.

During the second phase of development of this type of lamp, so far only two types of glow discharge lamps have been produced, and these, though possessing a number of advantages, have not proved sufficiently perfect to warrant extensive use, but it must be remembered that the whole history of the development of the glow discharge lamp is very modern history, and that much in this field is still unexplored.

With increased facilities for production and study of rare gases, the increased knowledge of ionization of gases and phenomena of luminescence, the functions of the electrodes and behaviour of different materials used for them, and the phenomena of tube hardening, and with increased practical experience, new and more successful types of the glow discharge lamp will no doubt be produced.

It may well be that the glow discharge lamp will ultimately prove to be the ideal electric light source which is being sought so eagerly by the illuminating engineering world.

CHAPTER VIII

AUTOMOBILE LAMPS. SPECIAL TYPES OF LAMPS

AUTOMOBILE lamps are quite distinct from the ordinary standard types owing to the fact that they are small and usually required to run on low voltage circuits, although a considerable demand exists for special patterns of small lamps for high voltage use where conditions necessitate particular effects, such as imitation candles.

Some idea of the numerous kinds of special lamps that the manufacturer has to deal with may be gathered from the fact that for car lighting alone there are twenty-four different shapes in daily demand, with ranges of 3 to 12 volts and from 1·0 to 80 c.p.

The general principle of the lamps of these special kinds are the same as vacuum or gas-filled lamps already described, but in the case of those of the tube variety, additional supports are necessary to hold the filaments in a position parallel to the tube. Such conditions necessitate hand work of very careful nature, both in the manufacture of the skeleton and in sealing together. In addition, it often happens that caps have to be fixed on both ends of the tube, a necessary addition when such lamps are used for shop window or indirect lighting, where they are used in conjunction with half-tube reflectors, so arranged to fit snugly into corners.

Such lamps and those of the "candle" type, while giving a rather more artistic effect than the ordinary bulb shape, are rarely satisfactory in either efficiency or life, and are usually only used in connection with other lamps to give the desired effect combined with sufficient illumination.

The demand for such special designs while quite considerable collectively, is not often found to figure very highly in a manufacturer's output, but an increase in demand is being made for small lamps for motor and similar uses, where the greatest efficiency on low voltage circuits is absolutely essential.

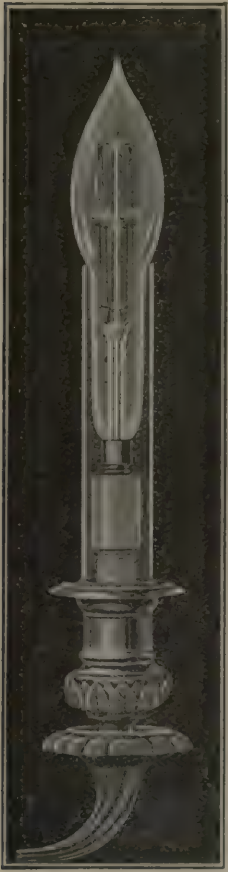


FIG. 23
CANDLE LAMP

Further, a small bulb must be used and the filament arranged in such a way that a close resemblance of "point source" effect is obtained, for automobile use at any rate.

The chief difference in design in such cases is with regard to the mounting of the filament, which is necessarily reduced to the shortest possible length, the result of which is that less support is required to hold the filament in position, so that in the majority of cases the joint is made direct on to the leading-in wires, which also serve the purpose of acting as support in a similar manner to that of the carbon lamp.

As already mentioned, most of the work is done by hand The bulbs are blown from tube by boys (not in the glass works but seated at benches) with gas blow-pipes directed away from the face. The rough bulbs are trimmed by girls, as with the ordinary lamps.

Stems are made in exactly the same way as in the larger lamps, from funnels, which are fixed with the leading-in wires in a revolving machine where a portion of the tube is melted and squeezed together, embedding the wires in a vacuum-tight joint. The chief difference is, of course, the absence of the stem or centre rod.

The filament is then joined to the leading-in wires by pinching the extremity of the two wires together, when the complete stem is ready for mounting in the lamp, which process has already been described.

Hand Lamps. Under this heading come lamps used for miners, police lanterns, and so forth where conditions are somewhat liable to rough usage. The size of the bulb varies from 26 mm. down to the ordinary pocket flash lamp bulb. Voltages range from 8 to 2, with an efficiency of about 1·0 watts per candle. The filament is naturally short and is mounted between the leading-in wires in the form of a slight arc. With flash lamps, part of the bulb is often made opal to give as much reflection directly in front as possible.

Flash lamps are made at small cost, particularly in Japan, where labour is cheap. The equipment necessary is not very elaborate, at any rate compared with that for lamps of higher wattage. Further, the life and efficiency are not so exacting. In actual use, flash lamps rarely run more than an hour or two, yet the total demand runs into many millions a year, both in Europe and America. The current consumption is naturally small, about 0·15 to 0·6 amps., otherwise the strain on the dry cells used would be too much, with the result that the battery would be exhausted. Types of special low voltage lamps have been given in the foregoing specifications, but for automobile use other standards have been adopted for use on cars of the chief makers. On a "Daimler" 30 h.p., for instance, it is recommended to use 36 c.p. headlights, 9 c.p. sidelights, and 6 c.p. rearlights on the 12-volt circuit. A general analysis will give the result that 70 per cent. of the known makers of cars use a 12-volt supply, half of which use 24 c.p. headlights.

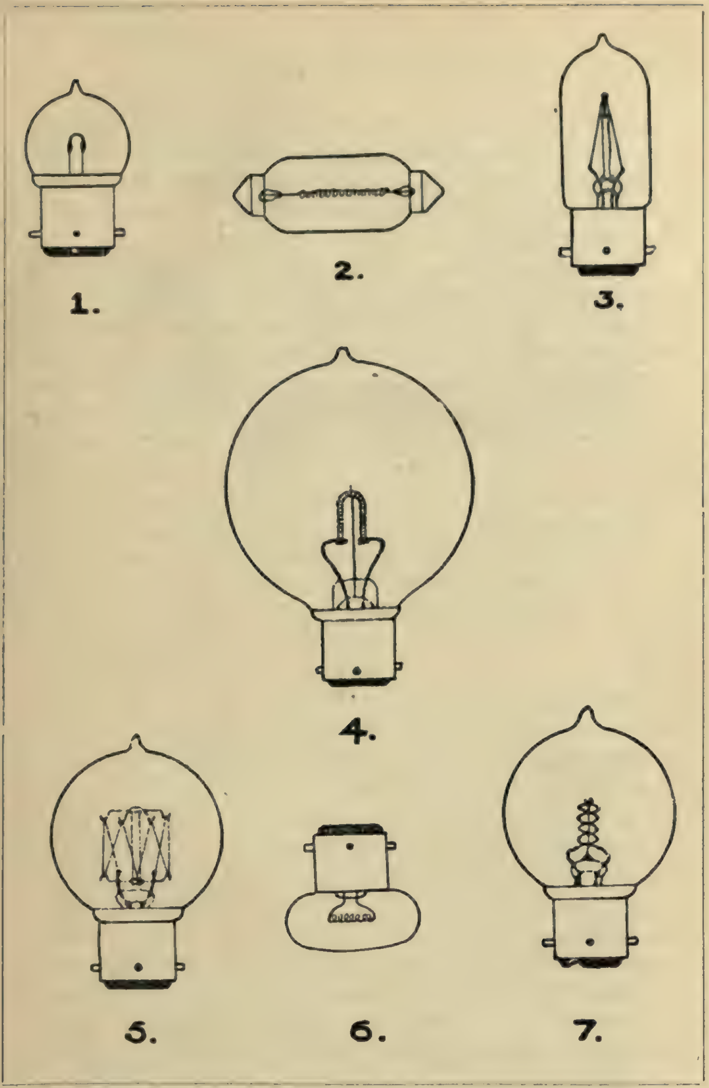
Now it must be remembered that several important factors are introduced in car lighting which have been referred to previously, but not in actual detail.

It is necessary to collect the light emitted from every part of the filament and concentrate at a point source considerable distance ahead of the car. The light must be penetrating and, therefore, as white as possible, but without undue glare.

The "point source" effect of the filament aimed at is obtained by means already described, but the design of the lamps is important, in this essential, that it must be possible to utilize the point. If a concentrated filament is mounted in a bulb of six inches diameter (to take an extreme case for illustration), it will require special lenses and reflectors to make use of the light for projection, but, on the other hand, if the bulb is too small, its life and efficiency will be impaired, due to premature blackening.

With either a mangin mirror or parabolic reflector, either of which is used, with or without additional lenses, a very small adjustment will give a parallel or divergent beam at will. But it is necessary that the filament is so placed in relation to the wall of the lamp that sufficient focussing space is available between it and the reflector or lens. For this reason, most motor lamps are made with the filament close to the cap in a bulb of sufficient capacity to avoid overheating.

As with the standard lamps, the benefit of



Edison-Swan, Ltd.

FIG. 24

TYPES OF AUTOMOBILE LAMPS

" half-watt " effect has been applied to smaller units, a very great advantage for high efficiency, low voltage conditions giving, in consequence of the very much greater intrinsic brilliancy, the white, penetrating light so much desired.

Vacuum type, head, side and tail lamps are made for the same voltages, but consume about 1·0 watts per candle. The standards of the motor manufacturers are for 6 and 12 volts, but 4 and 8 volt lamps are used to a considerable extent. Rearlights are always a much lower candle power in comparison with the headlights.

CHAPTER IX

CAPPING OF LAMPS—TESTING

It is particularly unfortunate for the manufacturer that so many types of lamps of various candle-power, shapes and voltages, should be required, but, added to this, when the lamp, as a perfect lighting unit, has emerged from all its operations the great variety of fittings in general and domestic use make it necessary to have them furnished with a great variety of caps.

A few years ago as many as eleven different types (apart from size) of caps were used, but the gradual centralizing and standardizing of electrical fittings generally, has led to the use of two equally satisfactory designs, viz., the Edison Screw Cap and the Swan Bayonet Cap.

The former makes connection by an outer screw (which also serves to hold the lamp in position) and central button, but with the Swan or B.C. cap, contact is made independently of the cap itself, by two studs set in the insulator. To hold the lamp in position, two small pins, one projecting at either side of the cap, are provided, and after pressing into the holder which contains two spring contacts, a quarter turn of the lamp sets the pins in two slots cut in the socket to take them.

Caps, usually made of thin brass, are filled with an insulating material to separate the two contacts, otherwise serious short circuits and leakages of current would occur. The insulator must be hard, fireproof, waterproof, and chemically inactive toward the brass. Various substances have been tried at one time and another, but after many exhaustive trials it has been found that a very low fusing point glass, known as " vitrite," is the most suitable substance.

The shells are arranged in a mould with the stud or studs in correct position, and in the case of B.C. caps with pins projecting through the sides. Molten vitrite is poured into the shell up to a height of about one-quarter of an inch, when a plunger is brought down to force the plastic glass into shape and fix the contacts.

Although the material is termed glass, it is in reality only an enamel containing a high proportion of lead to give fluidity, and considerable quantities of manganese to produce a black colour.

The manufacture of caps is a trade by itself, very few lamp makers being willing to lay down plant, as the outlay is large and return small, except where hundreds of millions of caps are made.

Caps are necessary in every standard type of lamp, although the design may vary a little, and in fixing, care is necessary as the lamps have reached the final stage before marking and packing. It may not be apparent at first sight how this operation can affect the lamp, being a fixture on the outside and only connected to the stem and filament through the medium of the two copper wires in the seal. A description of the capping process will, perhaps, make this more clear.

The cement for fastening is usually composed of cement mixed with resin, shellac or similar gum in alcohol or its equivalent. A small quantity is laid in the shell and worked round with a knife to leave an even layer on the inside. The two wires of the lamp are threaded through and the cap brought flush up against the neck of the lamp, where it is held in position by spring clips and heated. After a moment or two the solvent evaporates, when the cap will be firmly cemented in position. If, however, the heating and quality of materials used in the cement are not carefully controlled, several troubles may arise—

(1) Loose caps.

(2) Cracked tops.

(3) Bad insulation—any of which immediately condemn what otherwise might be a perfect lamp.

When the collars are set, the copper wire leads are soldered to the brass (with resinflux to prevent corrosion) the superfluous wire being clipped off. The lamp is then complete and ready to be tested and marked. The testing may be done before capping, but it is much simpler and more rapid to deal with the finished lamp, as all that is necessary is to plug into a holder, while without the cap it means fastening both lead wires to the test apparatus and after measuring undoing again, often kinking or breaking the wire and making the capping more difficult.

Lamps are bought according to their so-called candle-power, a term very easy of misconstruction unless understood, but, in addition, questions of light distribution, surface illumination, colour analysis, and reflecting powers have to be determined for illumination purposes.

Light in itself cannot be measured directly, because light is only an effect of radiation of certain wave lengths comparable with an agreed standard of known wave lengths. One standard of candle-power is the effect produced from an area of five sq. mm. of melting platinum. Other standards consist of lamps burning pentane or colza oil at a given rate with flame of known height and diameter. The actual standards are not used in practice for comparison, but filament lamps carefully aged and compared with original standards are used, these again serving as standards for other lamps, so that from one careful laboratory test, hundreds of lamps are standardized, each and all only being comparisons used as standards to make other standards.

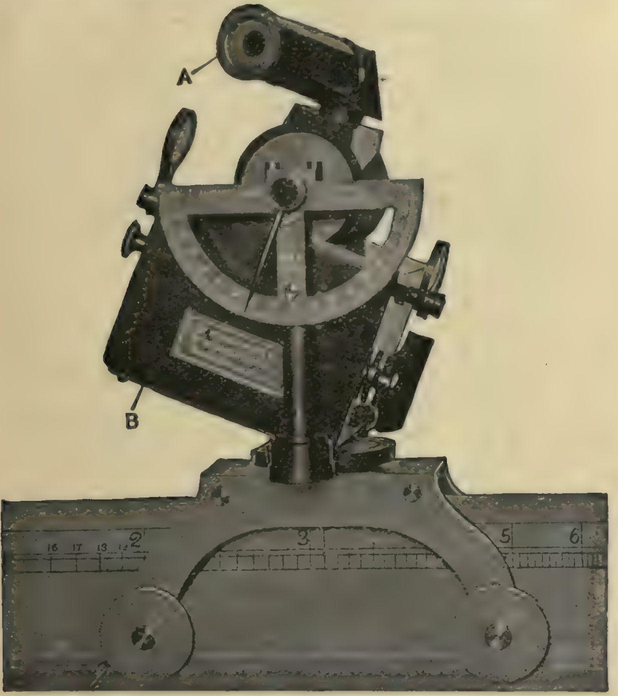
It will therefore be seen that photometry is a determination of considerable flexibility owing to the difference in colour and the introduction of individual error into each measurement. By perfection of instruments this error has very considerably been eliminated and may not, for all practical purposes, be taken into account, as other varying factors balance or eliminate any mistake introduced in the measurement.

By allowing the light from a standard lamp to fall on to a white surface at 45°, a certain quantity is reflected, and if a lamp with candle-power unknown be similarly placed, but so arranged that both reflections may be viewed at the same time, as illustrated, then by moving either the lamps or reflecting surfaces in the same plane, a point is reached when both reflectors appear of the same intensity. By measuring the distances from the screen of each lamp, the candle-power is determined by the following equation: $\frac{L}{S} = \frac{A^2}{B^2}$ where L is the candle power of the lamp to be tested, S, c.p. of the standard lamp, A and B the respective distances from the lamps to the screen.

Commercial photometers in the factory have to be fool-proof as far as possible and capable of rapid working. The candle-power is read off direct from a scale, while the current and voltage are at the same time indicated in full view.

Where colour comparison results are required, the flicker photometer is sometimes used, in which the screen rotates very rapidly, first showing the reflection of one lamp and then the other. While the illumination on one side is greater, a flickering effect is produced, which disappears when the balance is effected.

The light value of the lamp is usually given as mean horizontal candle-power, indicating that in the case of a 100 c.p. lamp the light radiated in a horizontal line from the luminous portion of the lamp would be a hundred times as great as one standard candle at an equal distance. This is very misleading, as lamps may give considerably more light in one direction than



Alexander Wright, Ltd. FIG. 25

FLICKER PHOTOMETER

another, so that determinations made in different directions and then averaged would give a much truer idea of the light given for known consumption of current.

It is often necessary, where particular effects are wanted, to plot out the "polar curve" or chart of distribution of light. Curves of this kind show at once the comparative quantity of light in different directions, so that lamps may be quickly selected which are suitable for street, shop, domestic or other purposes. Further, by using carefully designed reflectors the light can be concentrated on to a particular area or diffused according to necessity.

If the total light in all directions is to be considered, the photometry is conducted by means of a closed sphere, with the exception of the opening for the photometer, and of a uniformly white reflecting surface. With the lamp under test, which is hung in the centre, the intensity of the light throughout the inner surface is uniform in intensity and may be measured as a mean at a distance of the radius of the sphere. By this means an average spherical intensity can be measured at one reading. An additional advantage of this type of instrument is the fact of being able to measure the light flux of illuminants, such as the Moore Tube and vapour lamps, which, while possessing low intrinsic brilliancy are of high efficiency, but would have to be photometered at a considerable distance to obtain anything like a point source of light.

Difficulty is often experienced when comparing light of different colours, a difficulty encountered in measuring the half-watt lamps. In this case a calibrated screen is often used to bring the colour of the lamp being measured to that of the standard, but a method also adopted is to increase the temperature of the filament and calculate the radiation from a given area. By using Langmuir's equation very excellent results can be obtained—

$$\text{Temperature} = \frac{11230}{7{\cdot}029 - \text{log intrinsic brilliancy in c.p. per sq. cm.}}$$

For instance, at a temperature of 2,800° C. the intrinsic brilliancy of a tungsten filament is 1,200 c.p. per sq. cm., while the ordinary vacuum lamp only gives 150 c.p. per sq. cm., so that knowing the area and measuring the temperature, the candle-power may be directly determined; also, knowing the temperature, the dominant wave length may be calculated, so that lamps can be measured in terms of wave length of light.

With all the various methods of determination of candle-power where the voltage and amperage are measured against the illuminating power, the comparison is with a light of as similar a nature as possible. Comparison cannot be accurately made between a red light and a blue light, yet the efficiency may be equal.

The object of light is to provide a means of seeing, and it is, therefore, reasonable to say that the best test of a lamp is the distance at which objects can be discriminated.

An instrument, known as the luminometer, although somewhat crude in principle, measures light in terms of usefulness, and not in ratio to a standard. Although it has the reputation of being crude and unscientific, it is the only correct light-measuring instrument, and the photometer correct only so far as it agrees with the luminometer, but where luminometer and photometer disagree, the photometer is wrong, as it gives a comparison which is different from the one shown by the lights in actual use for illumination.[1]

The luminometer consists of a black box, something

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[1] Steinmetz, *Radiation, Light and Illumination.*

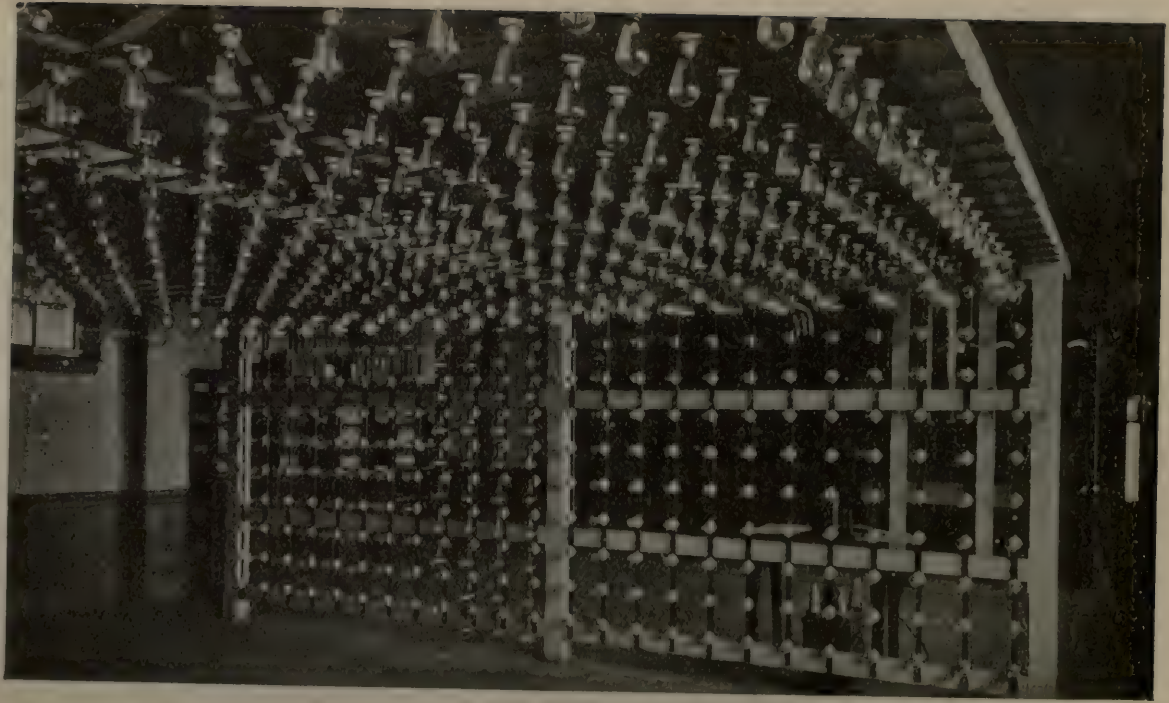

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FIG. 26

AMERICAN LAMP TESTING LABORATORY

like a reflex press camera, so that the light may be allowed to fall on to a sheet of printed letters and observed without other light entering the box. The observer moves, or the light is moved, until large letters are visible, while the smaller letters are not so distinct.

With different coloured lights and observers, results are found to agree particularly well, so that the personal error is no greater than in the use of the ordinary photometer, but it has the disadvantage of not being suitable for use over a very wide range.

In addition to the actual measurement of efficiency, further tests are carried on, not with all the lamps, but with samples taken at random from manufacture. A number are put on time trial under conditions such as the lamp will be subjected to in commercial use. During the trial the lamps are carefully photometered each day and a record kept of the wattage, candle-power, and life in hours. This is an important routine test, which soon indicates anything radically wrong in the manufacture.

The completed and tested lamps, set in trays according to their voltage and candle-power, pass from the final treatment of marking, and, if required, frosting (which is done with various compounds of hydrofluoric acid), after which they are handed over to the sales department of the factory, which is not, may it be said, the most difficult part of the " Electric Lamp Industry."

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